Fig 1: System Layers
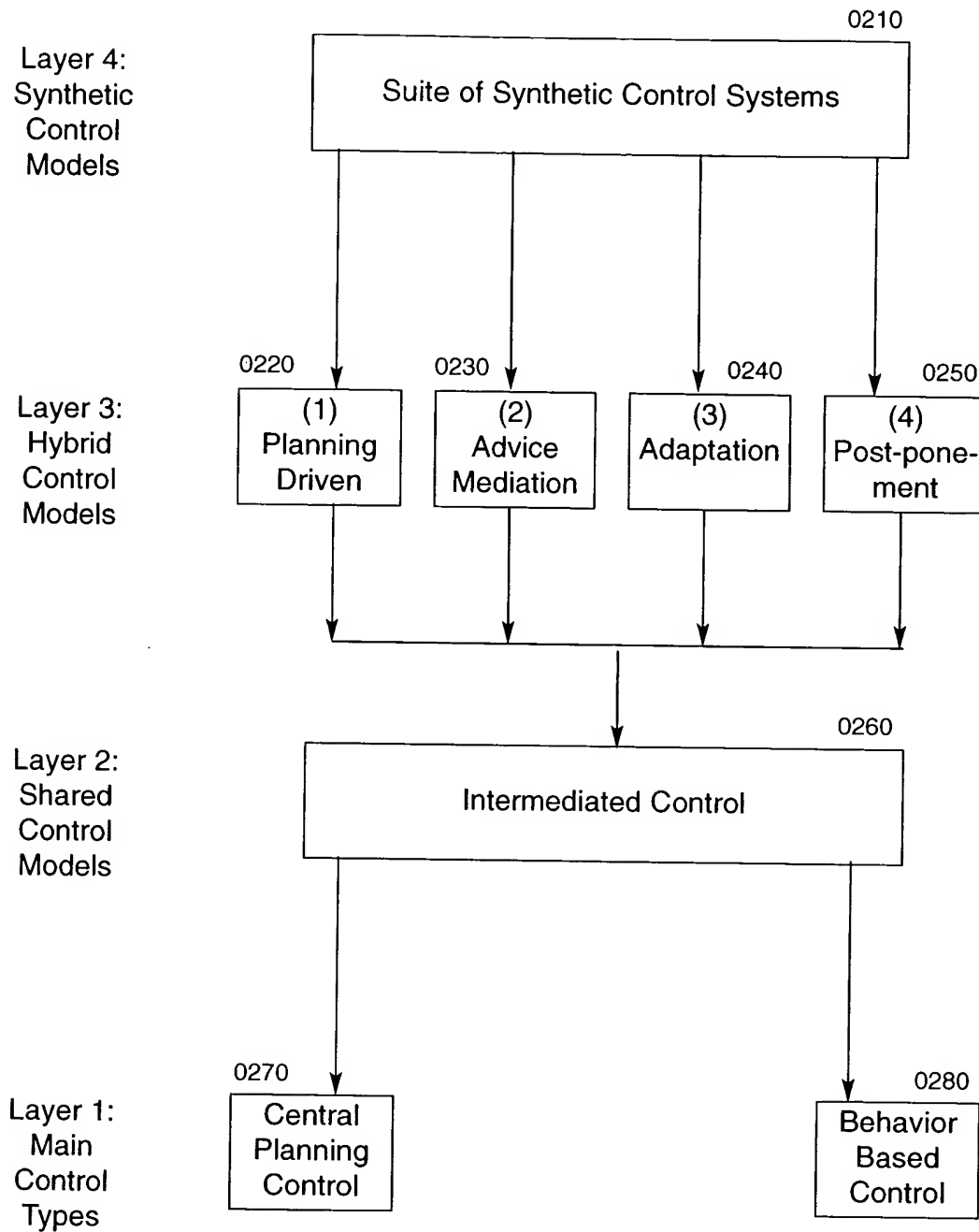
8. Functional Applications

7. Cellular Automata (CA) Simulations

6. Multi-Agent System (MAS) and Intelligent Mobile Software Agents (IMSA)

5. Omni-Nodal Evolutionary Artificial Neural Network (EANN)

4. Dynamic Distributed Object Relational Database Management System (ORDbMS)

3. Flexible Mobile Grid Computing Architecture in Dynamic Clusters

2. Distributed Mobile Robotic System (MRS) for Mobile Robotic Agents (MRAs)

1. Second-order Synthetic Hybrid Control System (HCS) for Mobile Robotic Agents (MRAs)

Fig 2: MRA Synthetic Hybrid Control System Architecture

Layer 4:
Synthetic
Control
Models

0210

Suite of Synthetic Control Systems

Layer 3:
Hybrid
Control
Models

0220

(1)
Planning
Driven

0230

(2)
Advice
Mediation

0240

(3)
Adaptation

0250

(4)
Post-pone-
ment

Layer 2:
Shared
Control
Models

0260

Intermediated Control

Layer 1:
Main
Control
Types

0270

Central
Planning
Control

0280

Behavior
Based
Control

Fig 3: Dynamic Database Organization

Modular Architecture / Type	One Unit	Distributed Network	Mobility
MRAs in MRS	Hardware agent ORDb data organization	Distributed computers (Data management within network) Sharing ORDbs (sharing data organization functions)	Mobile robotic agents with changing spatial positions
IMSAs in MAS	Software agents that analyze, decide, and negotiate	Mobile groups of interacting software agents	Limited range of IMSA interactions within wireless mobile robotic agent network
Evolutionary Artificial Neural Networks	Computation resource management	Continuous restructuring of network grid to maximize computation power	Wireless mobile grid of flexible network rewiring as it adapts to environment

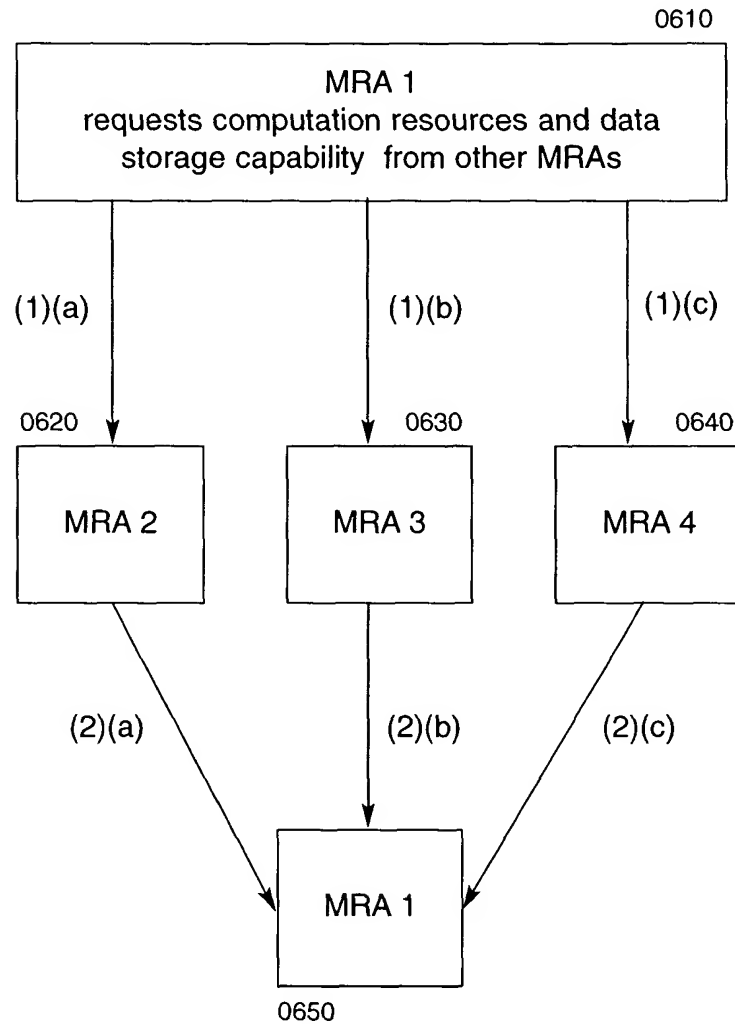**Fig 4: Identifying MRA Locations With Sensors**

0410

MRA
1

0420

MRA
2

MRA
3

0430
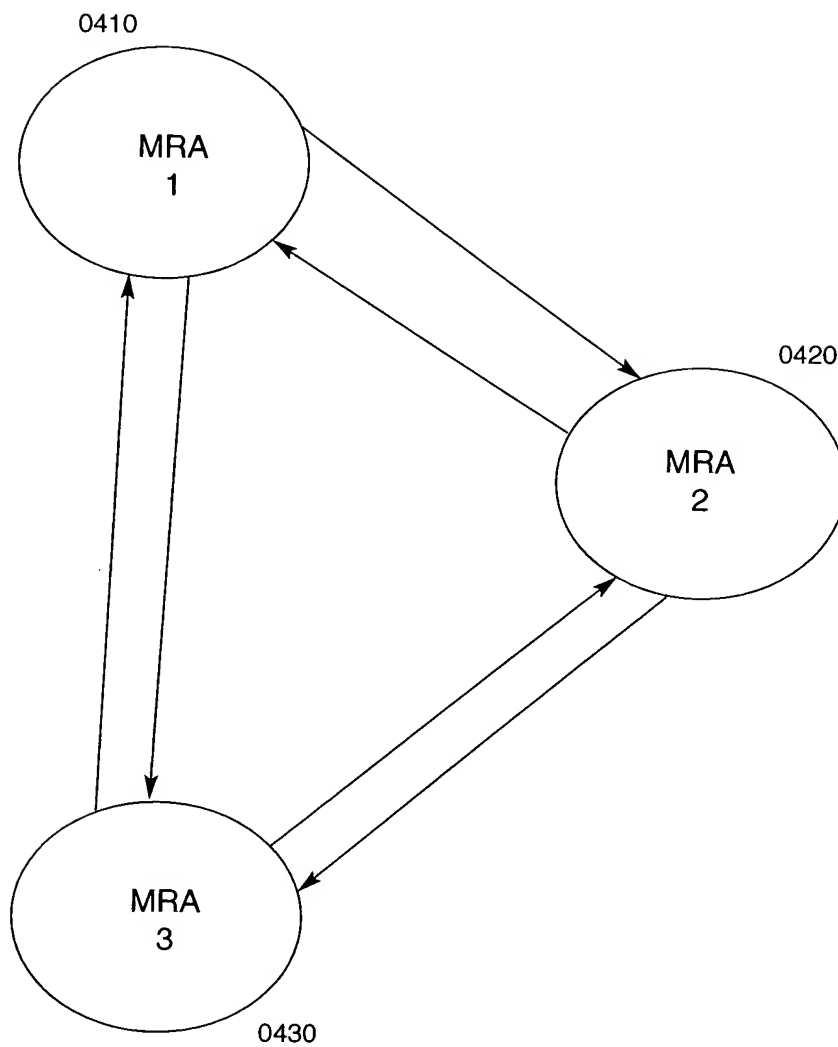
Fig 5: Assessing Environmental Situation and Coordinating Change in MRA State

0510

Sensor
detects
object

0520

MRA

Object

Change
in MRA
position

MRA

0530
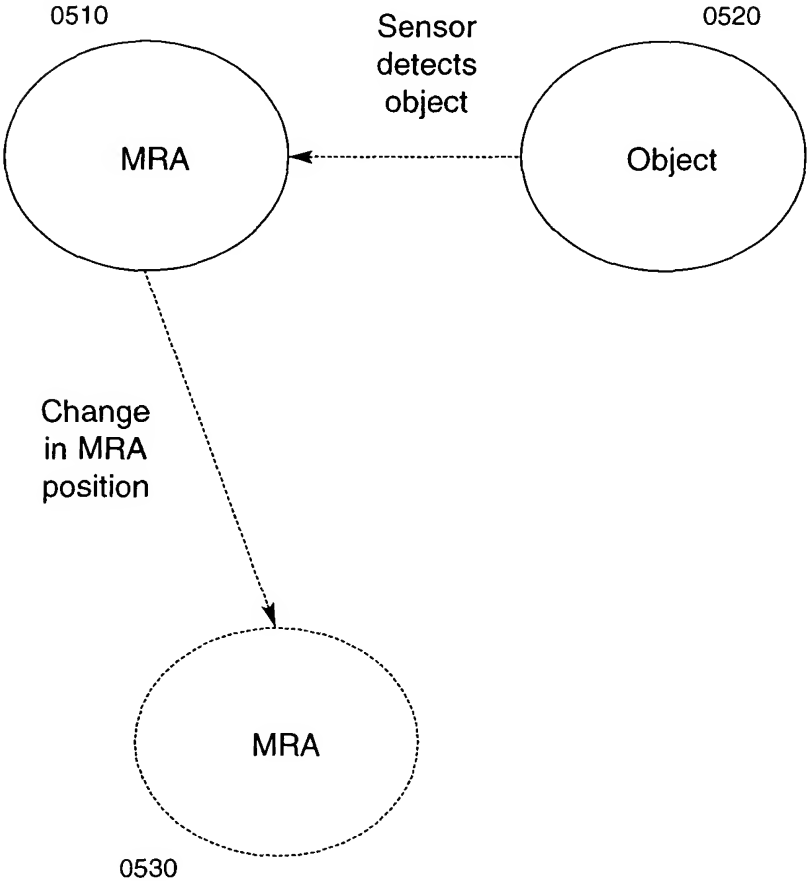
Fig 6: Metacomputing Model for Distributed MRS:
Flexible Mobile Grid Architecture in Dynamic Clusters

0610

MRA 1
requests computation resources and data
storage capability from other MRAs

(1)(a)   (1)(b)   (1)(c)

0620   0630   0640

MRA 2   MRA 3   MRA 4

(2)(a)   (2)(b)   (2)(c)

MRA 1

0650

Fig 7: Sharing Computation Resources Among MRA Nodes in Wireless Mobile MRS: Efficient Routing of Database and Analytical Functions

Status
messages in

Resource request
messages in

0710

Report status
distributor

0720

Request
coordinator

0730

MRS

0740

Cache

0750

Data
Stream

0760

Analytical
functions

0770

Messages out

Messages out

Fig 8: Database Coordination in Distributed MRS

0810

Front
end

0820

Query
initiator

0850

Data
sources

0860

Data
sources

0830

Query
executor

0870

Buffers

0840

Output
queues

0880

Fig 9: Dynamic Distributed Object Relational Database
Data Flow Process

0910

Query
Origination

0920

DB1   DB2   DB3   DB4   DB5

0930

Sensor data
streams

0940

Data
sources

0950

Query
executor

0970

Buffers

0980

DB1   DB2   DB3   DB4   DB5

0990

Output
Queues

Fig 10: Temporal Objects in ORDbMS

1010

Query
generator

1

1020

Query
executor

2a

6a

5

DB 1

1030

Data object undergoes
temporal change, is
tagged & given
temporal priority

1040

2b

3a

4

6b

DB 2

3b

Data
object

1050

7

1060

8

1070

Query
manager

Fig 11: Mobile Grid Dynamics

1110

New data informs analysis

1120

Interpretation
of data to
decide where
to move

Data sets
to informs
analysis

Move to new position to
get new data

Get new data analysis

(mobility)   1130

(Change in position to
collect data)

Fig 12: Autonomous Blackboards For MRAs

Phase one

1210

MRA1	MRA2	MRA3	MRA4
Spatial position (Latitude, longitude) Altitude Direction vector Speed	Spatial position (Latitude, longitude) Altitude Direction vector Speed	Spatial position (Latitude, longitude) Altitude Direction vector Speed	Spatial position (Latitude, longitude) Altitude Direction vector Speed

— · — · — · — · — · — · — · — · — · — · — · — · — · — · — · — · — · —

Phase two

1220

MRA1'	MRA2'	MRA3'	MRA4'
Spatial position (Latitude, longitude) Altitude Direction vector Speed	Spatial position (Latitude, longitude) Altitude Direction vector Speed	Spatial position (Latitude, longitude) Altitude Direction vector Speed	Spatial position (Latitude, longitude) Altitude Direction vector Speed

Data set changes from phase one to phase two

Fig 13: IMSA Operations Control of MRAs

1310

1320

Collaboration agent

Interaction process

MRA 1

MRA 2

Search agent (1')

Search agent (1")

Analytical agent

Messenger sub-agent

Negotiation agents (2) & (3)) interact

MRA 3

1330
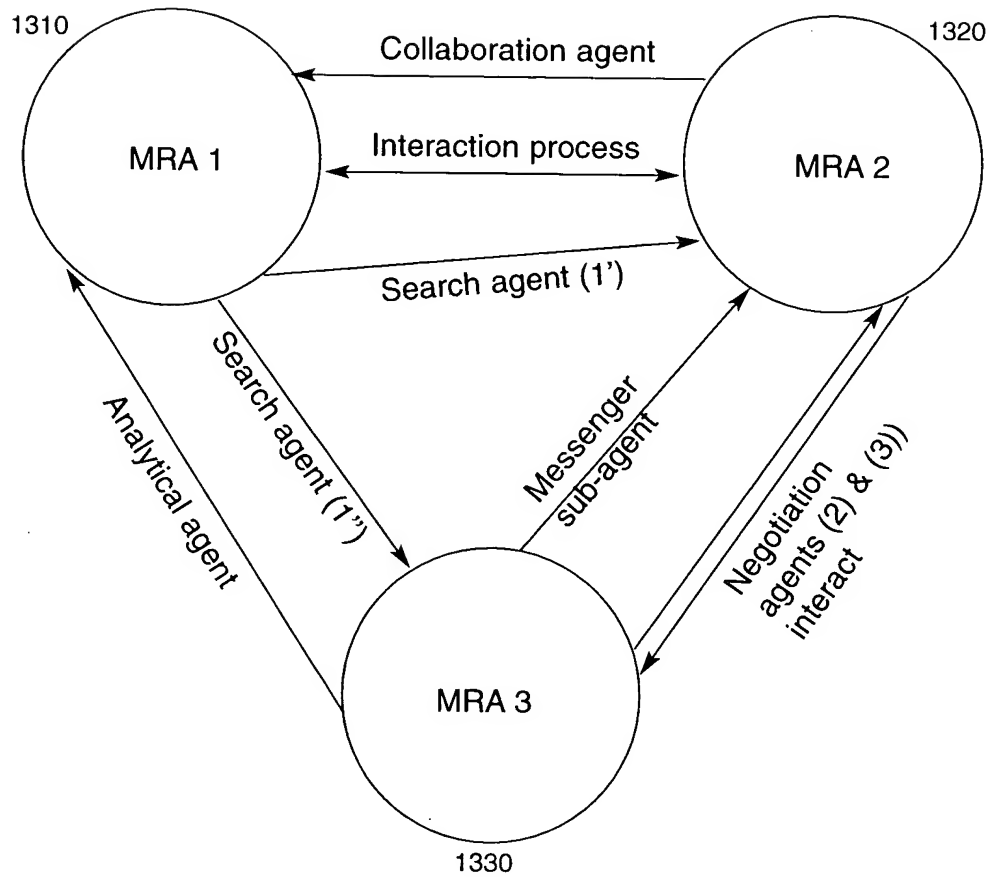
Fig 14: MRA Juvenile and Adult Training Levels

1410

MRA initiates
training exercise

1460

MRA employs learning
module with specific
tasks

1420

MRA adds
levels of
training exercise

1470

Refinement of
learning tasks

1430

MRA receives
various environmental
interactions

1440

MRA experiments with
environment &
improves learning with
positive reinforcement

1480

Juvenile training
level reached

1450

Adult training
level reached

Fig 15: MRA Attitude Biases

Behavior Spectrum

1510

Passive
behavior

1520

Normal
behavior

1530

Aggressive
behavior

Slower
judgement

Faster
judgement

Decision
with more
information

Decision
with information
constraints

Fig 16: Learning From Environmental Interaction: Adaptation

1610

MRA initiates
training exercise

1620

MRA interacts with
other MRAs

1630

MRA interacts with
environment

1640

MRA queries other
MRAs about specific
question

1650

As environment
changes, MRA
feedback changes

1660

MRAs access
database & respond
to data query

1665

Negative
feedback is
avoided
behavior

1670

Positive
feedback if
attractive
behavior

1675

Reinforce-
ment
learning

1680

Inter-MRA feed-
back as shared
information for
efficient learning

1690

Constantly
updated beliefs

Fig 17: MRA Training Process - "Experience" of Environmental Interaction Combined With Group Sensor Data

1710

MRA initiates
learning

1720

MRA accesses
sensor data from
other MRA team
members

1730

MRA accesses
environment
directly

1740

MRA collects
sensor data

1750

MRA analyzes &
interprets sensor
data

1760

MRA initiates
decision to act
based on data
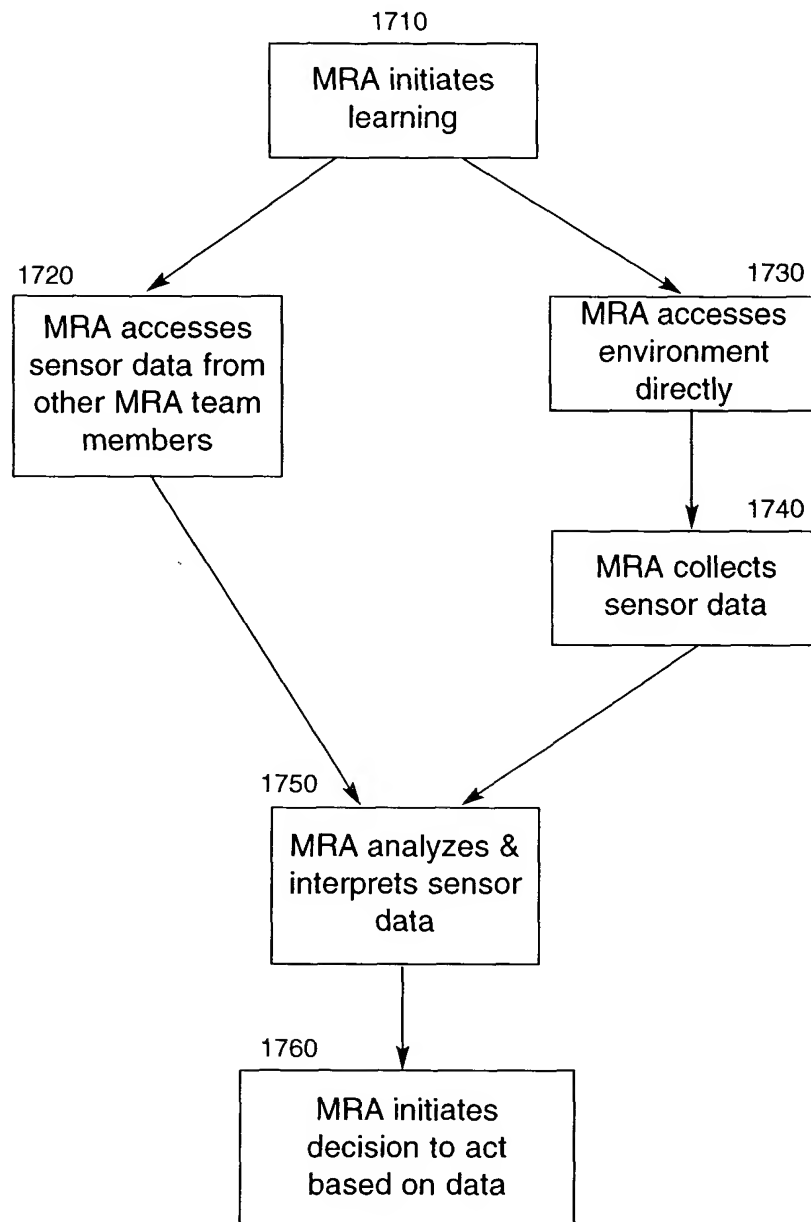
Fig 18: Reinforcement Learning:
(A) Intensity of Sensor Data and (B) Quantity of Sensor Data

1810

Sensor data input
into MRA

1820

Intensity of inputs
measured

1830

Quantity of inputs
measured from
different sources

1840

Compare inputs
to databases

1850

High intensity
input is provided
weighted value

1860

Large quantity of
inputs are assigned
weighted value

1865

MRA evaluates weighted
value from different sources

1870

MRA interacts with environment
based on input evaluation

1880

Intensity or quantity of inputs
reinforce specific behavior

Fig 19: Hybrid Learning Model With Time Constraints

1910

Data From Other MRAs

1920

Sensor inputs from environment

1940

MRA acts

1930

Data analyzed

1950

Positive feedback

1960

Interaction with environment

1970

MRA updates other MRAs

1980

Reinforcement of behavior in minimal time

1985

MRA establishes plan

1990

MRA implements plan by activating behavior
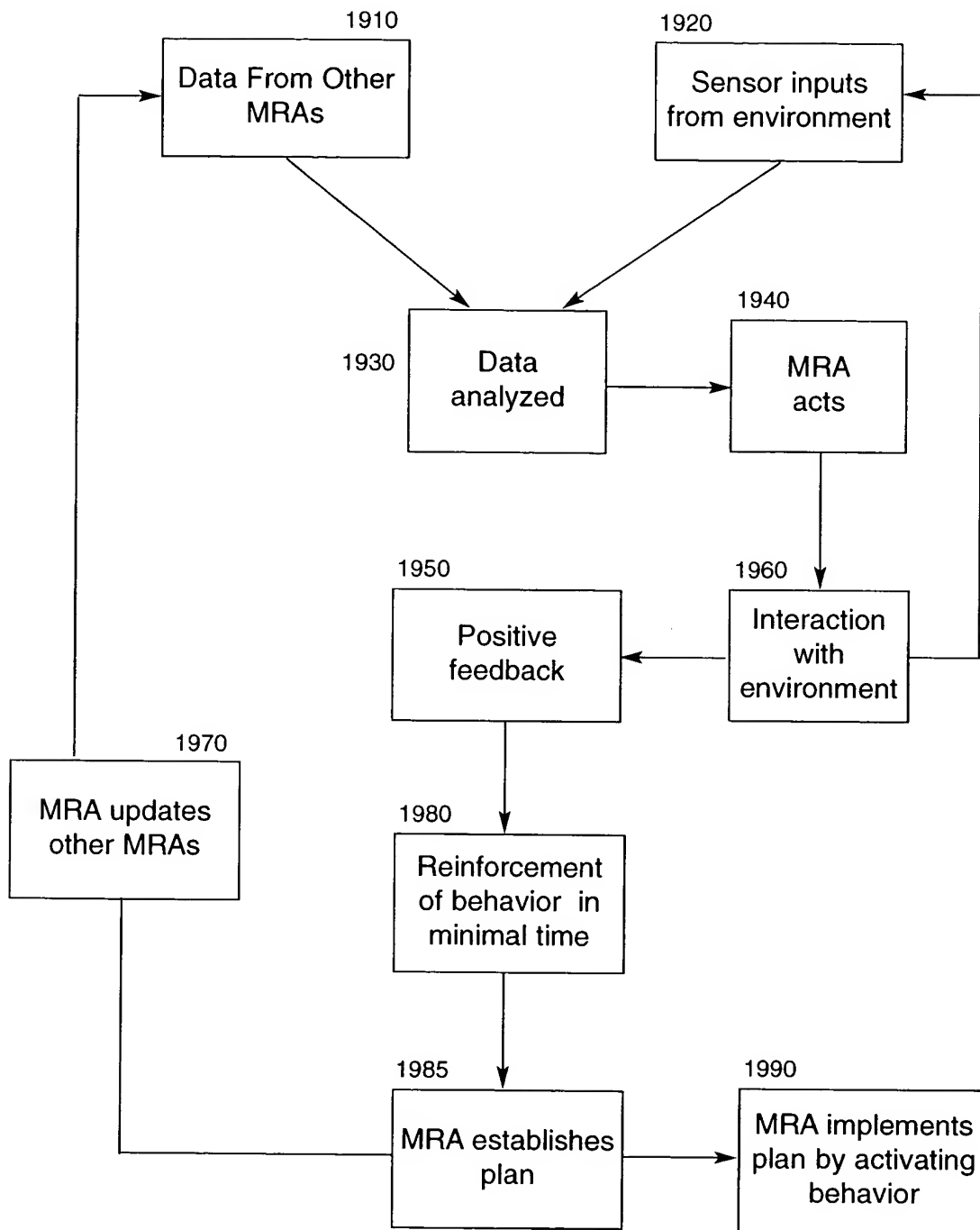
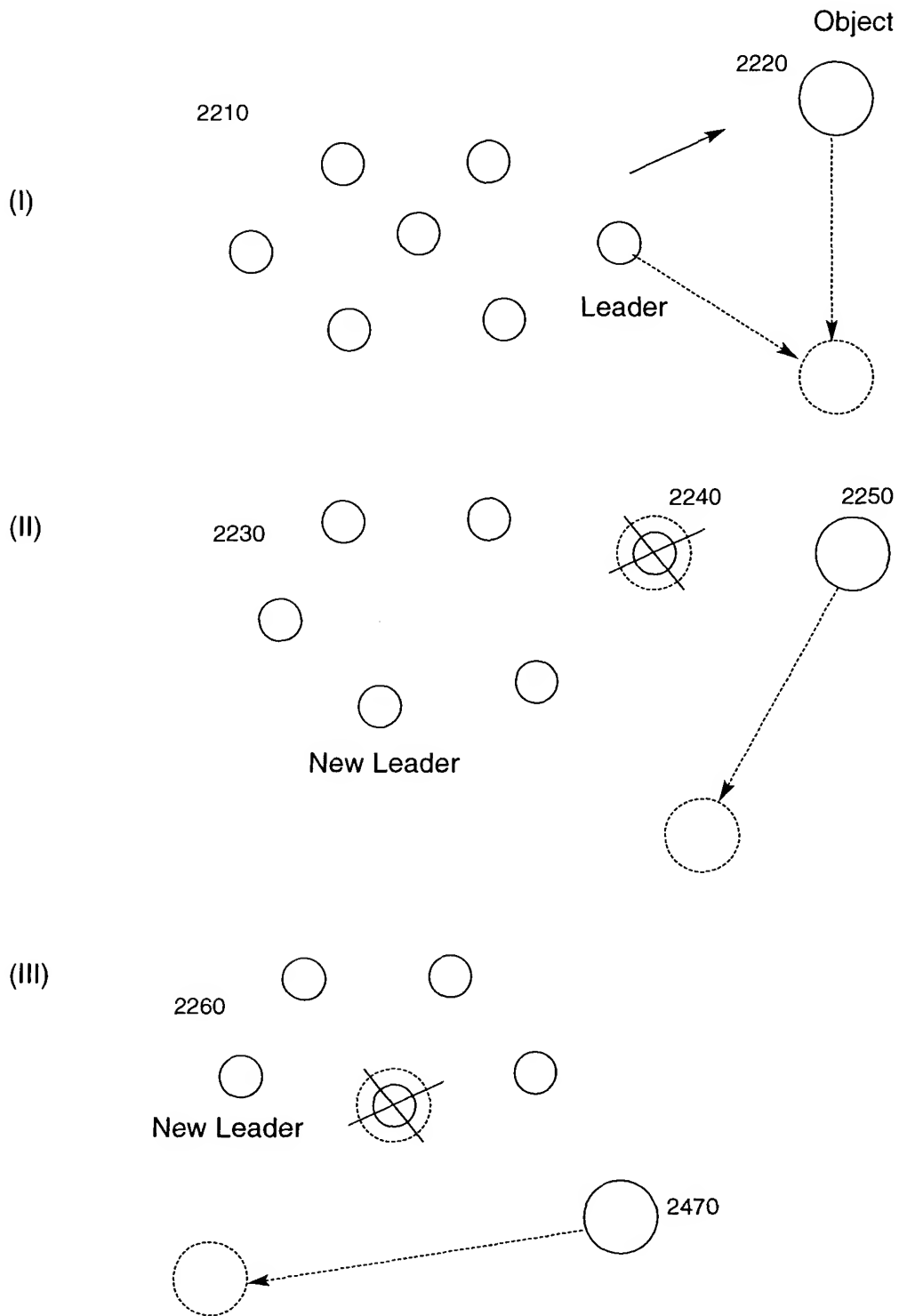# Fig 20: Social Learning: Learning From Inter-MRA Interaction
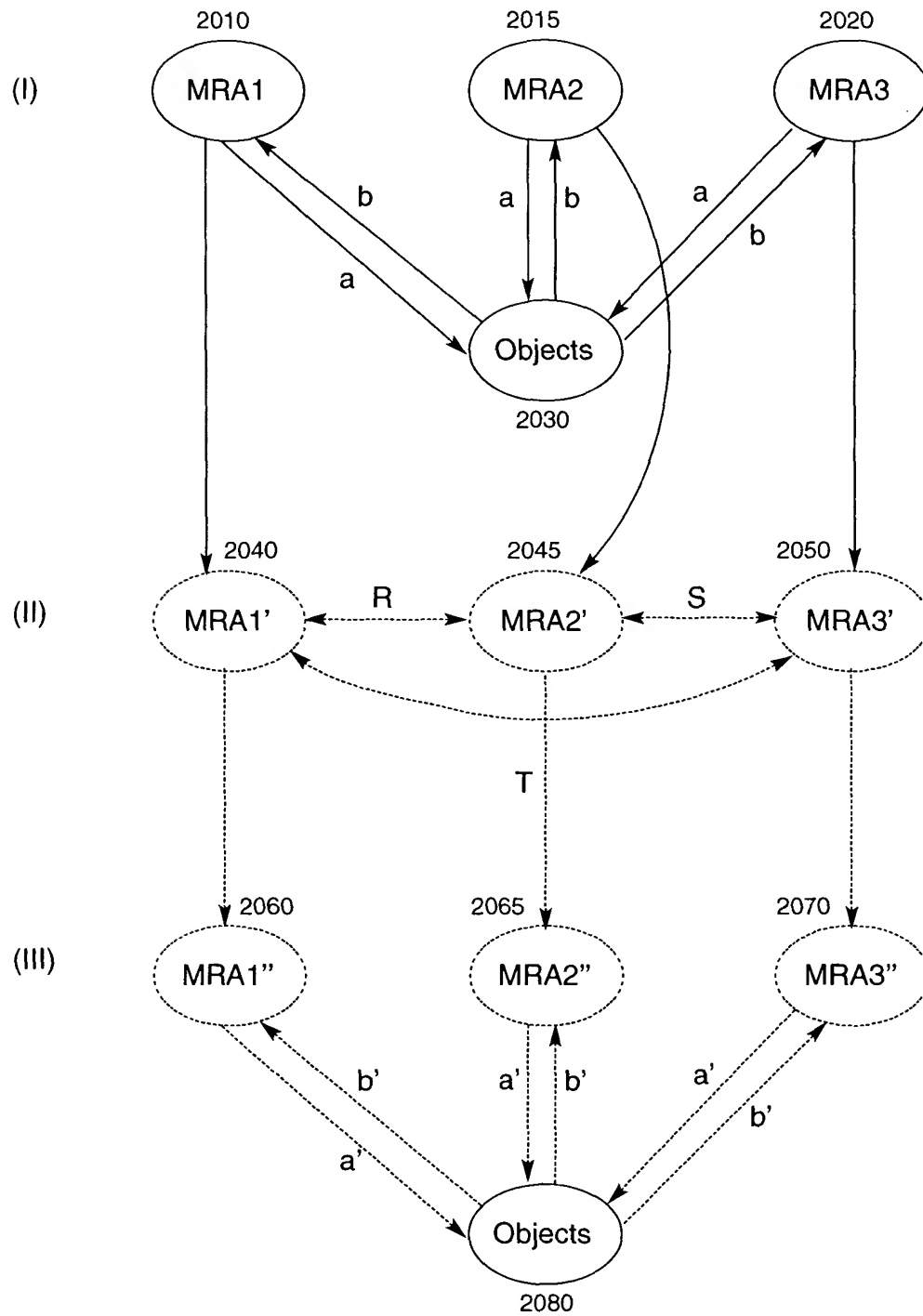
Fig 21: MRAs That Teach Other MRAs

2110

MRA1

Experienced
"adult" MRA

Initial request

2120

MRA2

"Student"
MRA

Provides IMSA
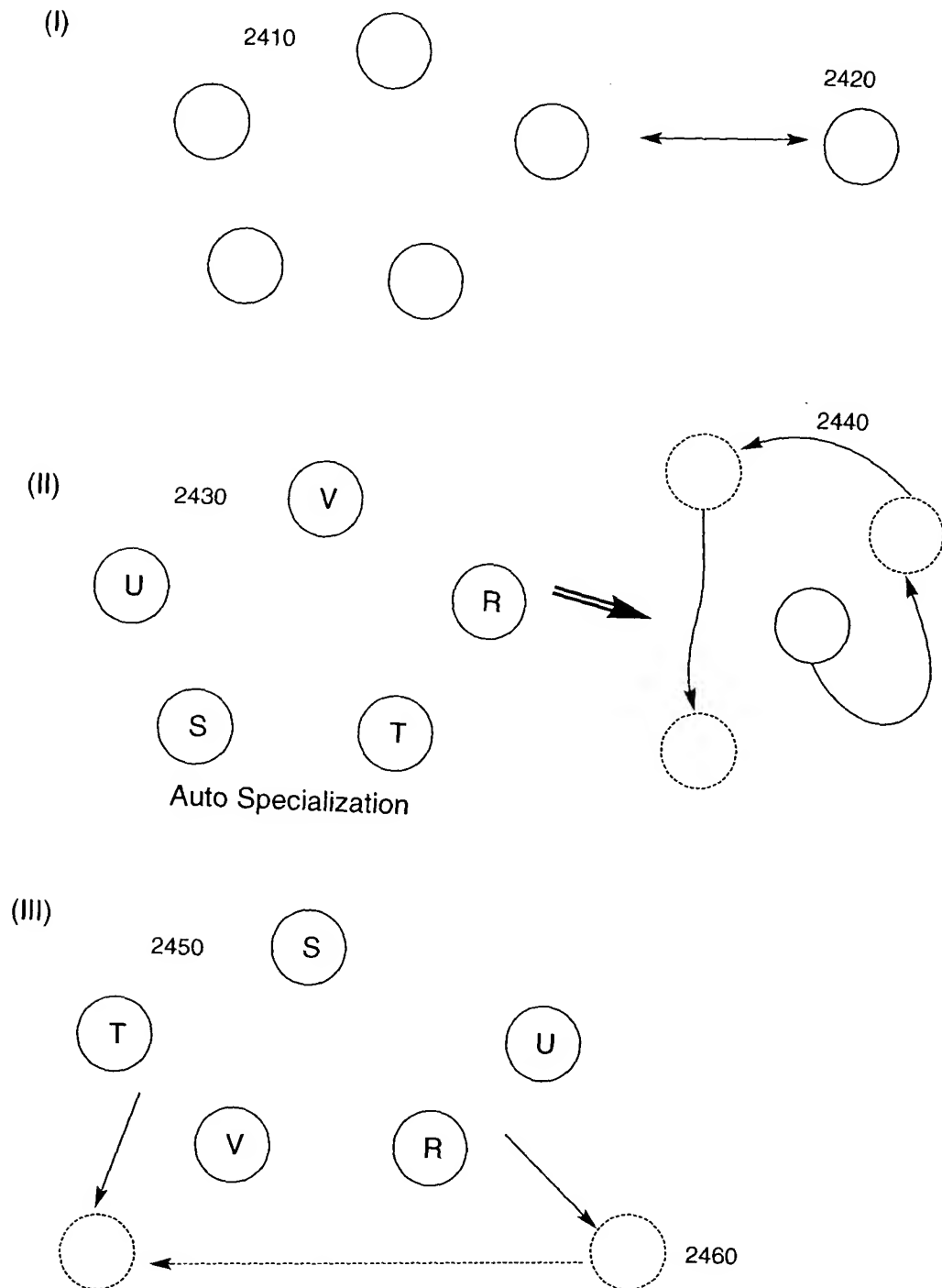with learning module

MRA1

2130
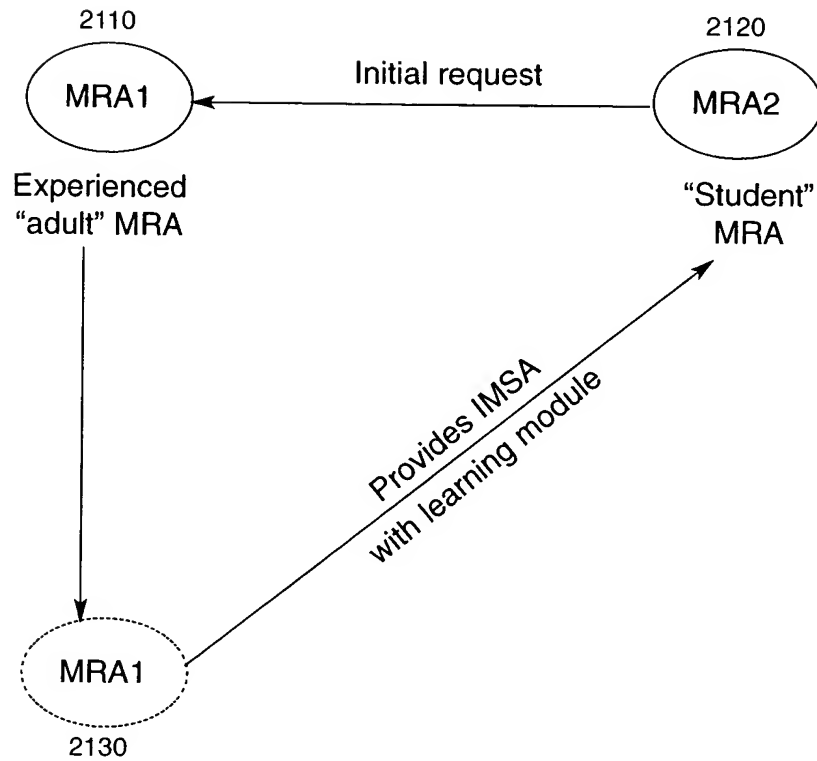
Fig 22: Asymmetric MRA Leadership and the Emergence of Temporary Hubs

(I)

2210

Object

2220

Leader

(II)

2230

2240

2250

New Leader

(III)

2260

New Leader

2470

Fig 23: Specialized Learning (in Teams): Division of Labor in Self-Organizing Groups

(I)

2310

R

Y

U

T

S

2320

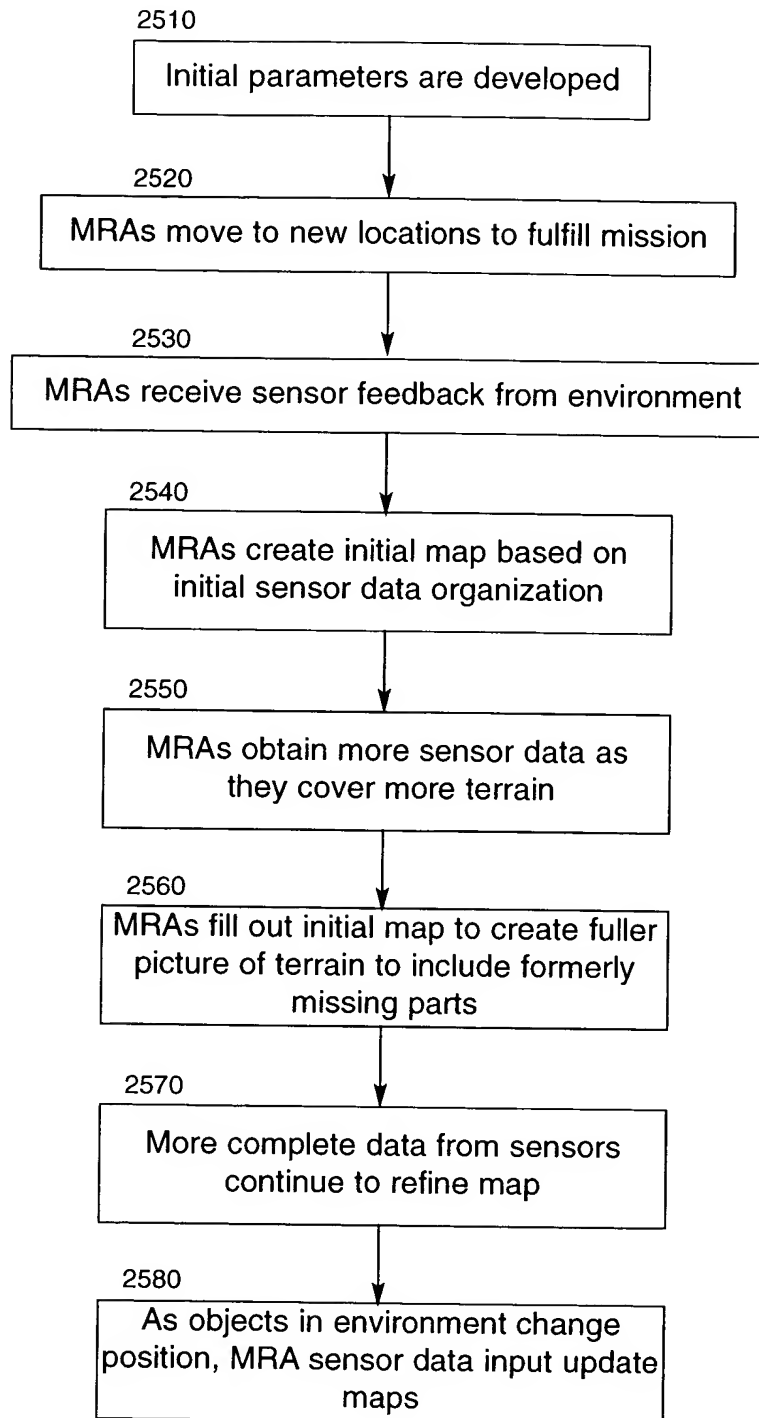Each MRA is a
specialist

(II)

2330

R

Y

U

T

S

2340

MRAs share data

Object
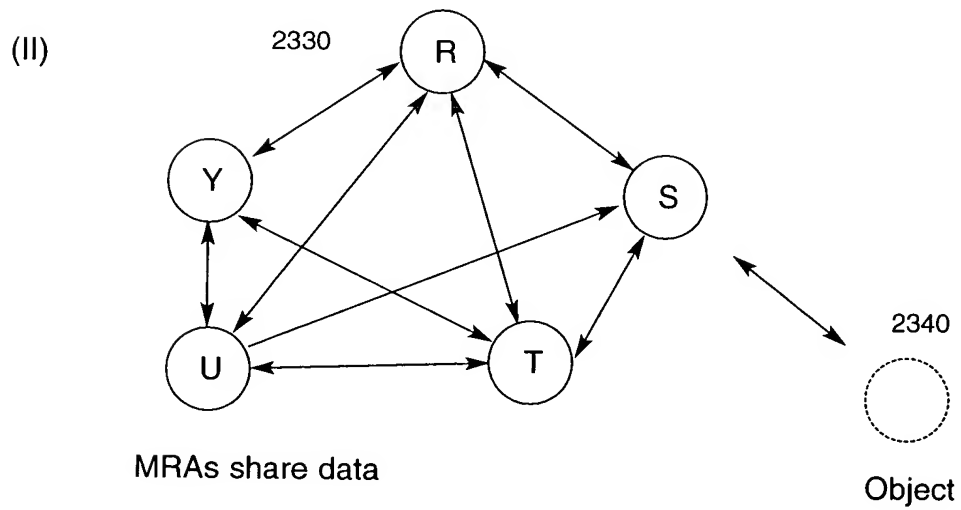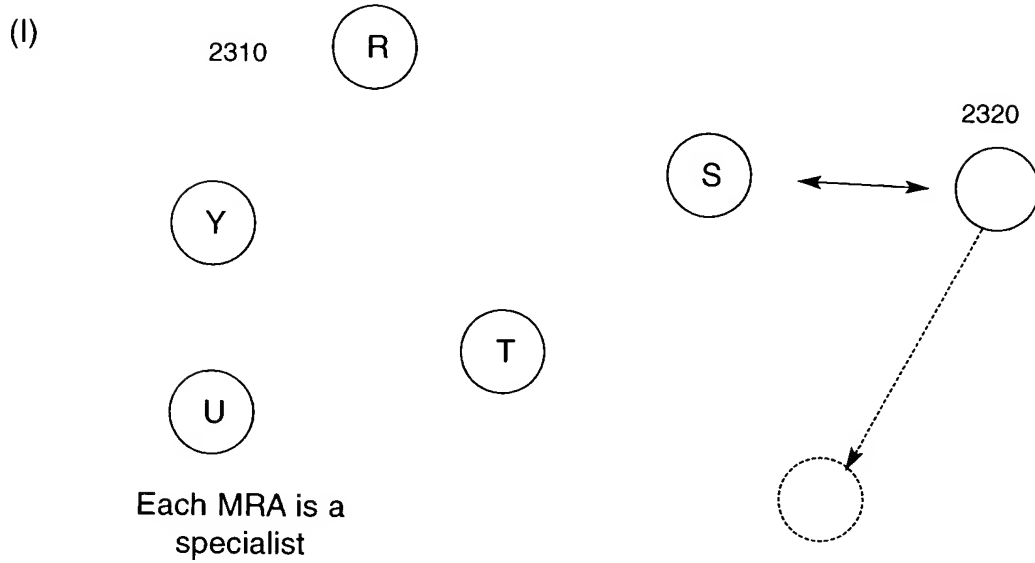
Fig 24: Auto Specialization: Self Organization by Task Division for Individual Specialization

(I)

2410

2420

(II)

2430

V

U

R

S   T

Auto Specialization

2440

(III)

2450

S

T

U

V   R

2460

Fig 25: Self Organizing Map

2510

Initial parameters are developed

2520

MRAs move to new locations to fulfill mission

2530

MRAs receive sensor feedback from environment

2540

MRAs create initial map based on initial sensor data organization

2550

MRAs obtain more sensor data as they cover more terrain

2560

MRAs fill out initial map to create fuller picture of terrain to include formerly missing parts

2570

More complete data from sensors continue to refine map

2580

As objects in environment change position, MRA sensor data input update maps

Fig 26: Flow Chart of Genetic Algorithm

2610

Create Population

2620

Add mutations to populations

2630

Evaluate fitness of each member of population

2640

Prune out weak members

weak

2650

Remove weak members from population

strong

2660

Select members for crossover using criteria

Create multiple generation -

2670

Perform crossover

2680

Insert successful candidates into population to replace weak members

Fig 27: Binary Genetic Algorithm Model

2710

1 0 1 0 1 0 1 0

2720

0 1 1 0 1 0 1 1

1 1 0 0 0 0 0 1

2730
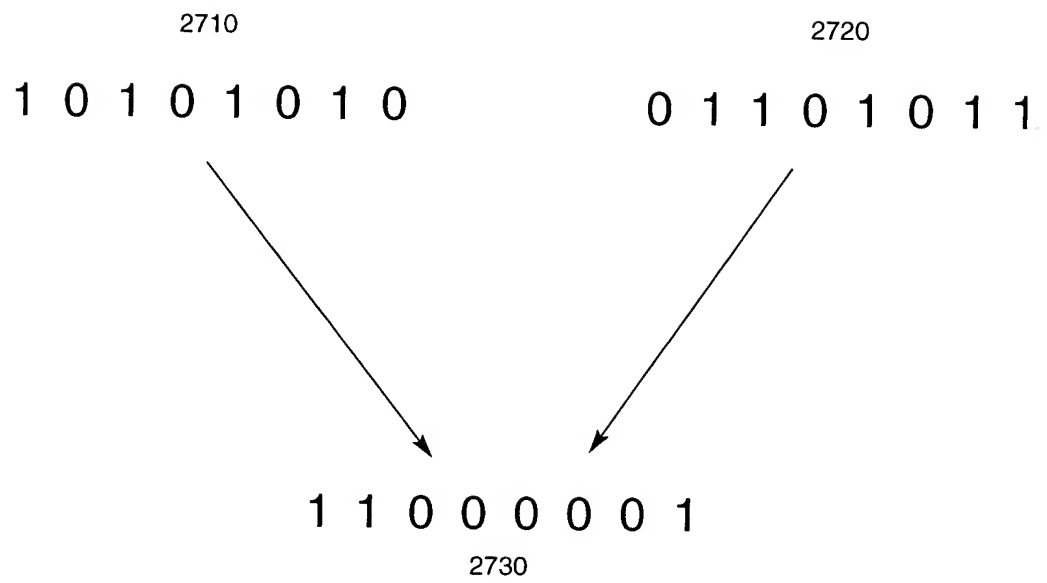
Fig 28: Tree Architecture - Genetic Programming Model

(I)

X1 2810

2830

X1

X0   X1

X2

X3   X1

2840

2820 X2

X0

X1   X3

2850

X3

X1   X2

(II)

X2 2860

2970

X3

X1   X2

X1

2880

X0   X1
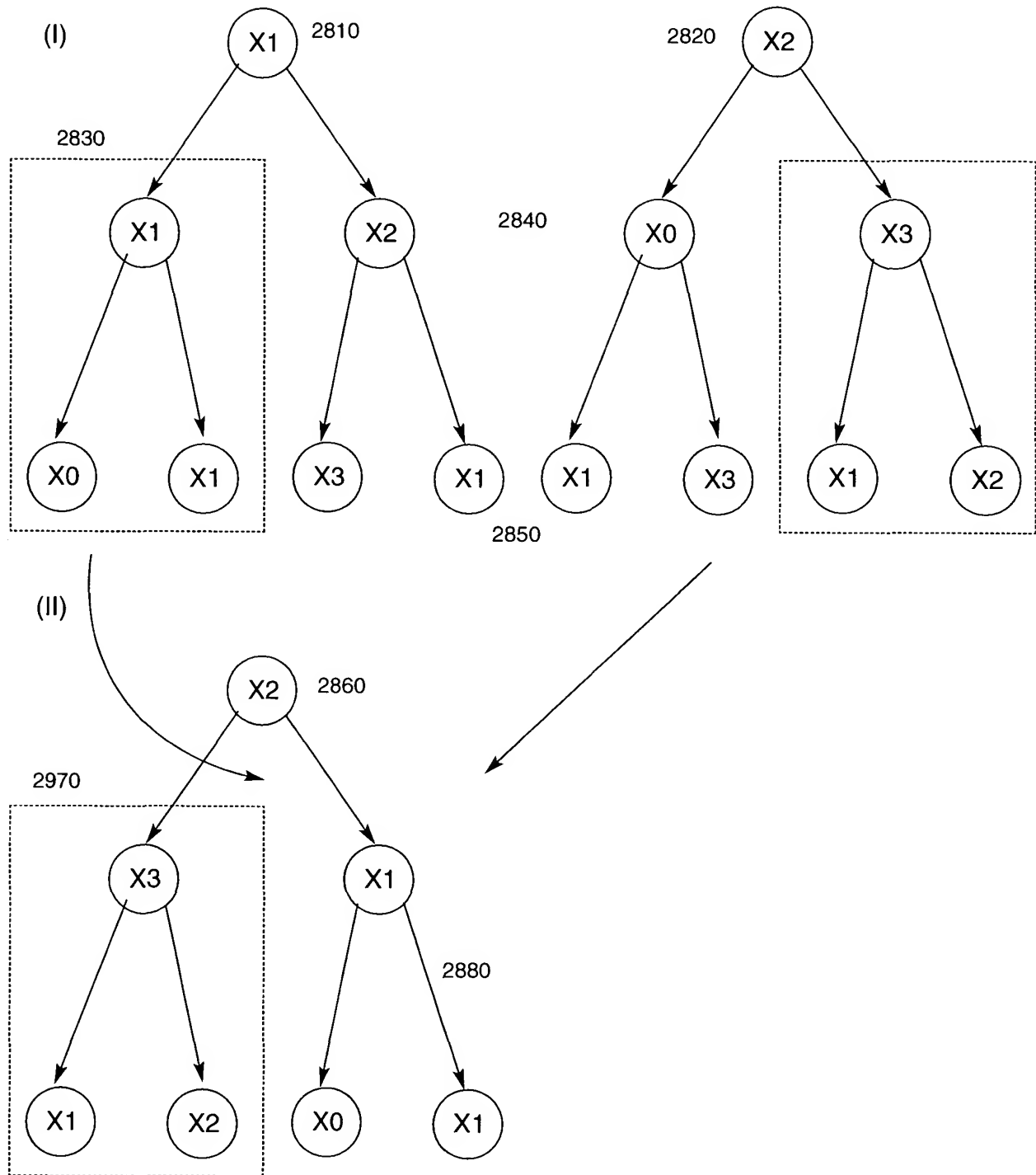
Fig 29: Parallel Subpopulations Fitness Evaluation

2910

2920

2930

2940

2950
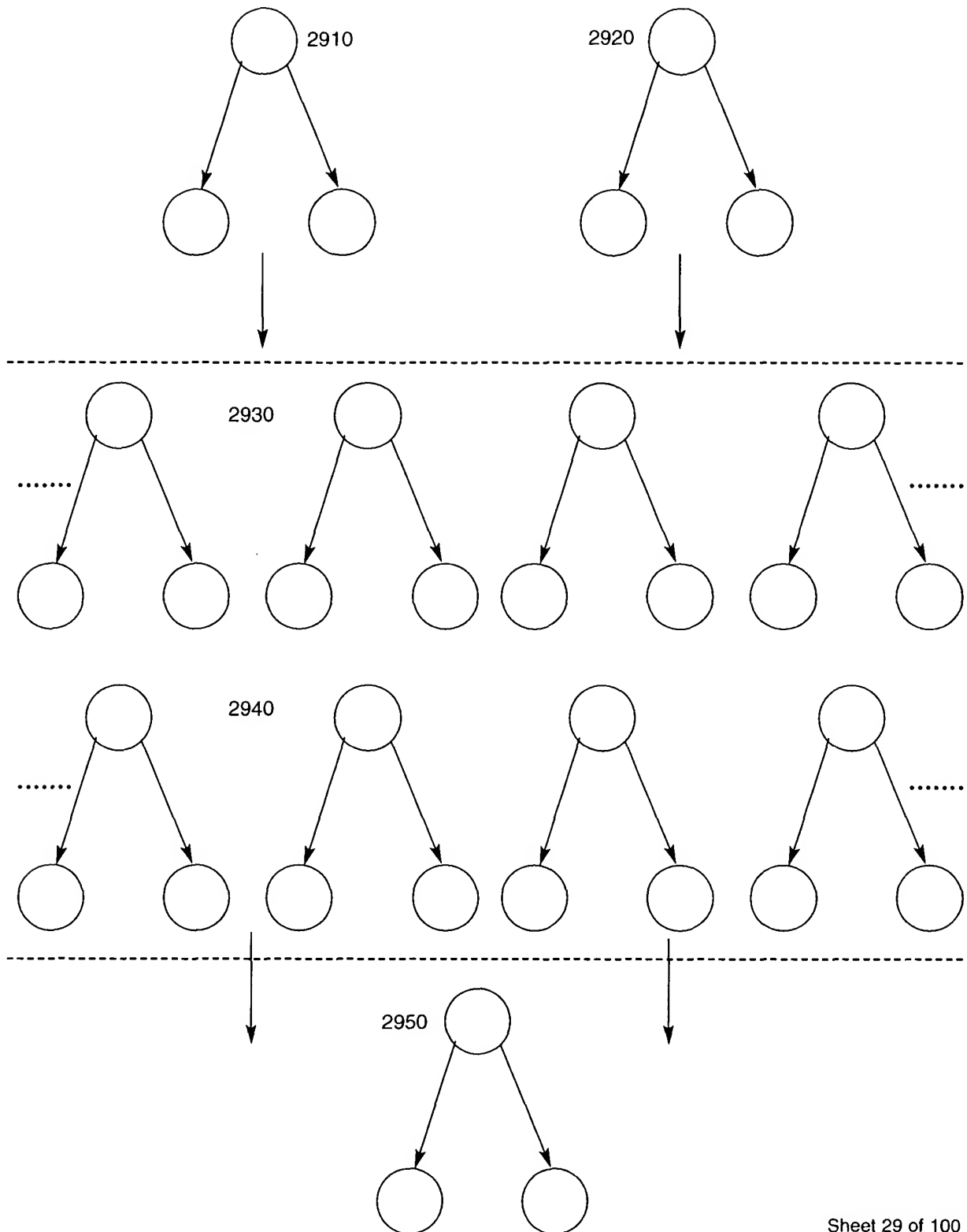
Fig 30: Two Layer Neural Network

3010

X

3020

X

X

X

X

X

3030

X

3040

X

X

X

X

X
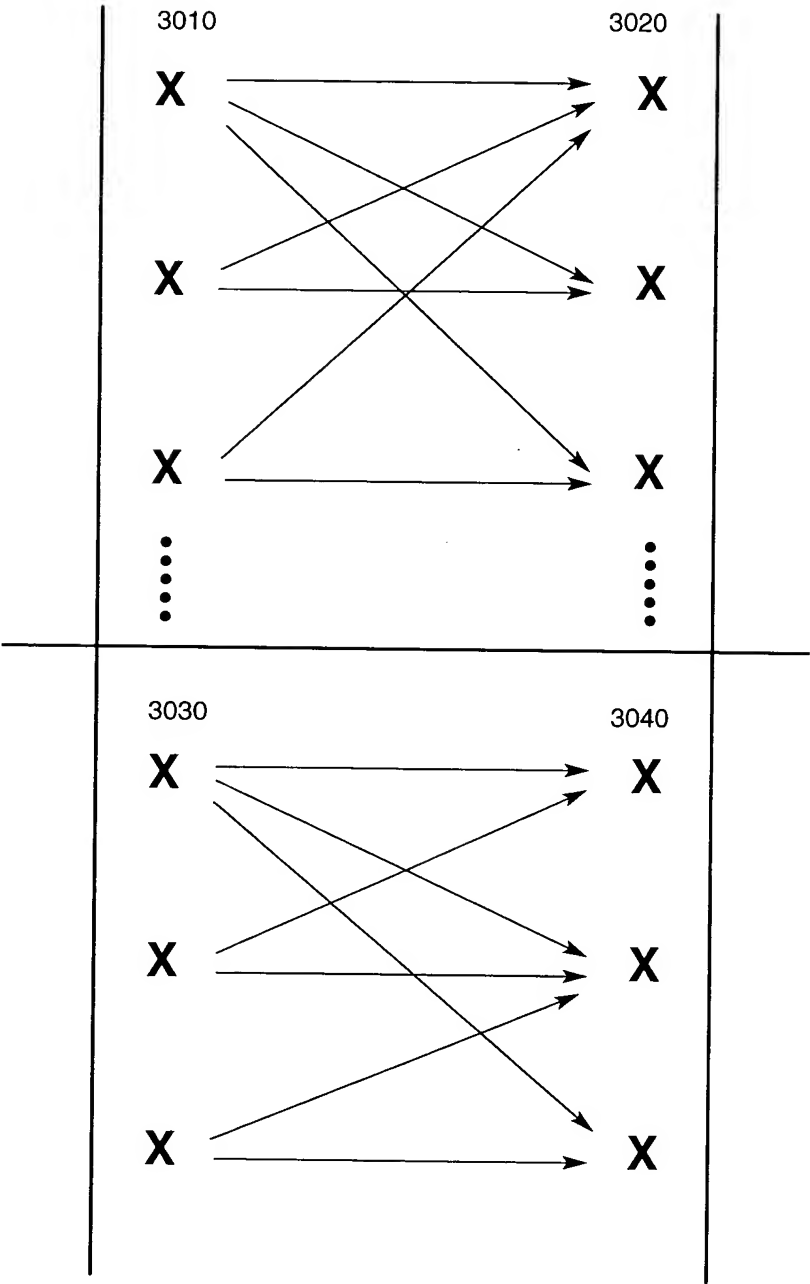
Fig 31: Artificial Neural Network Connection Weights
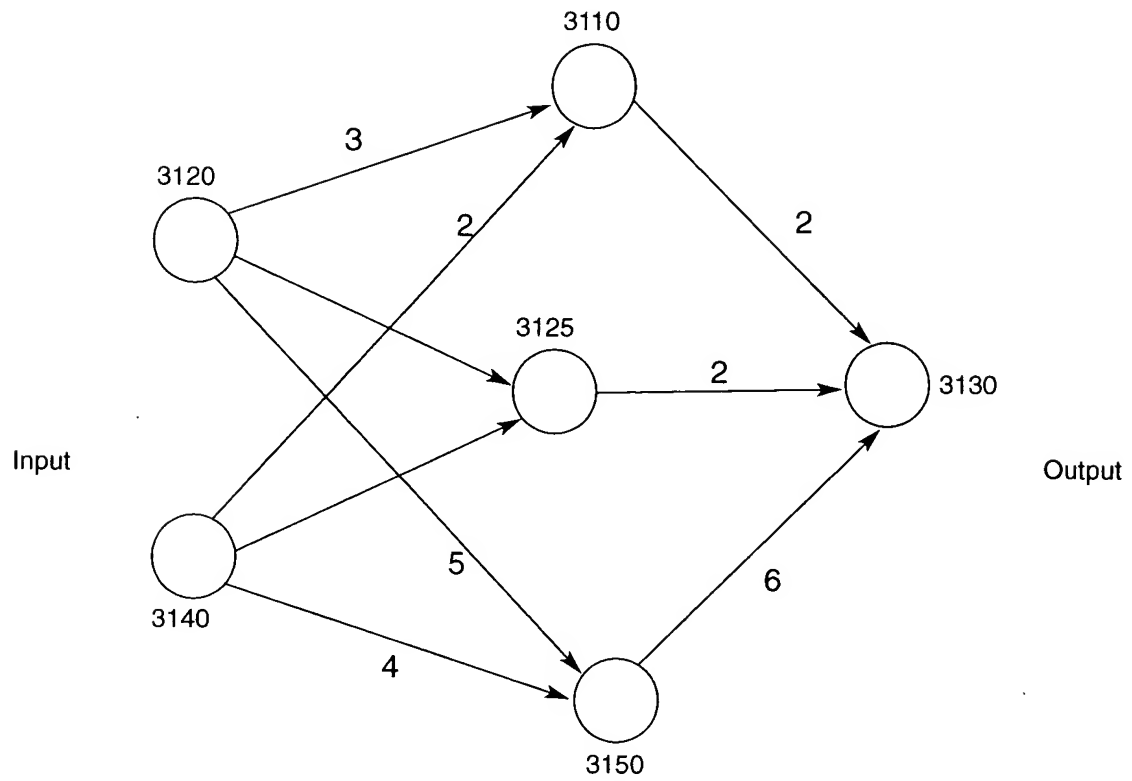
Fig 32: Genetic Programming Calculates Initial Weights

Inputs

3210

3220

2

1

3230

2

3240

4

3250

1

2

3260

Output
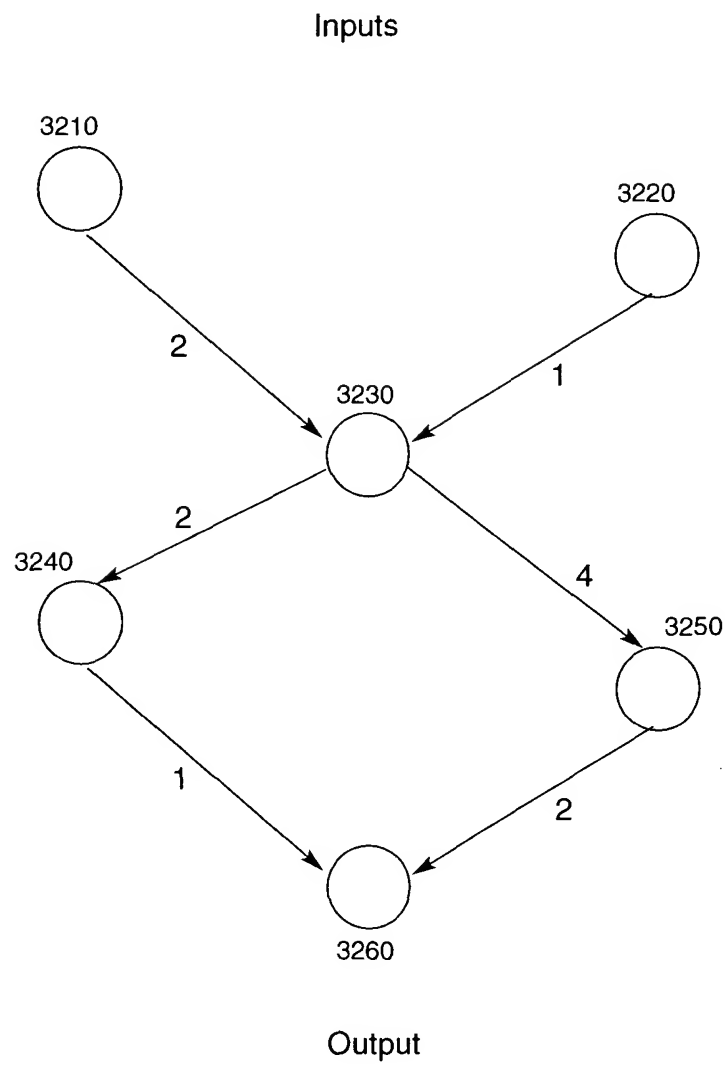
Fig 33: Genetic Programming Applied to Indeterministic ANN

(I)

3310

1.7

2.3

5.3

3315

3320

.3

3325

1.3

1.7

.3

3330

(II)

3335

1.7

3340

2.7

3.3

3345

2.3

5.6

3350

3355

3360

3365
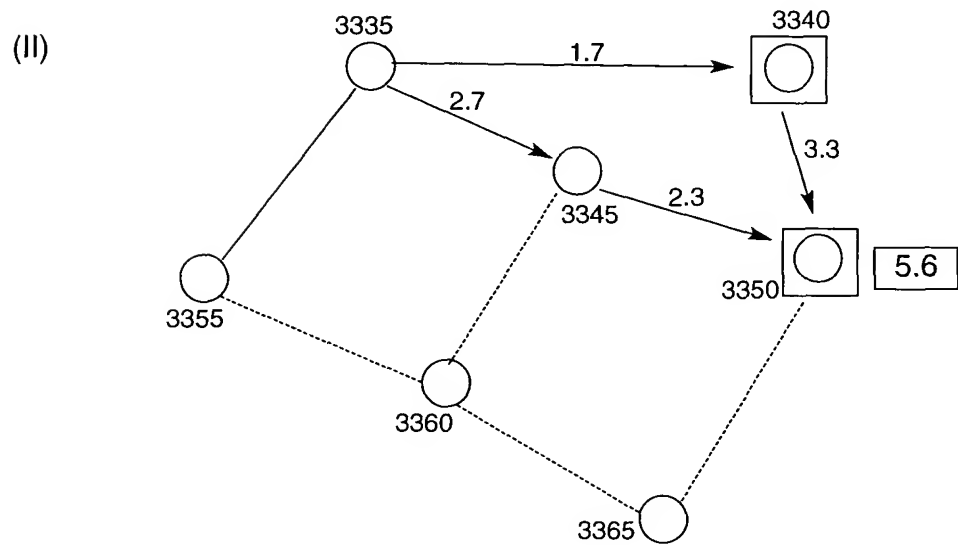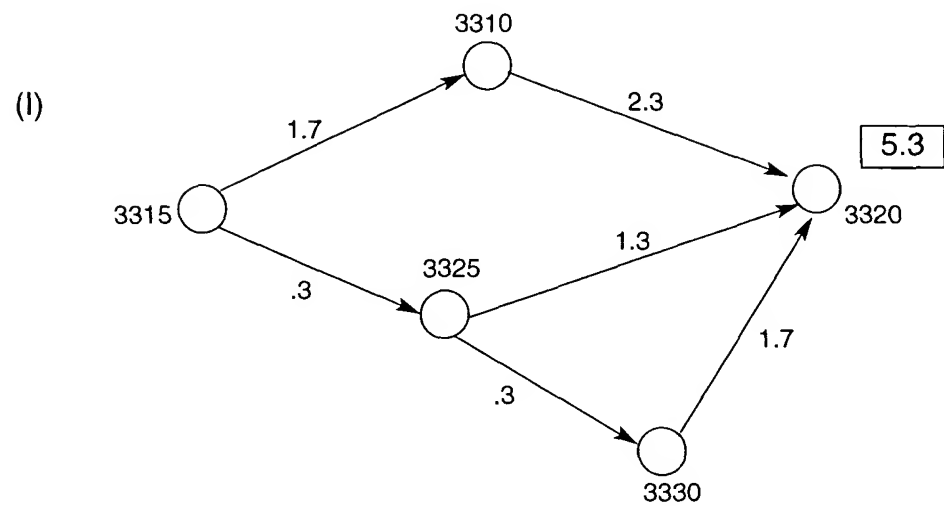
Fig 34: Neuroevolution - Evolutionary A-NN Connection and Node Additions

3410

3420

3440

Mutate:
Add Node

3450

3430

3460

Mutate: Add
Connection
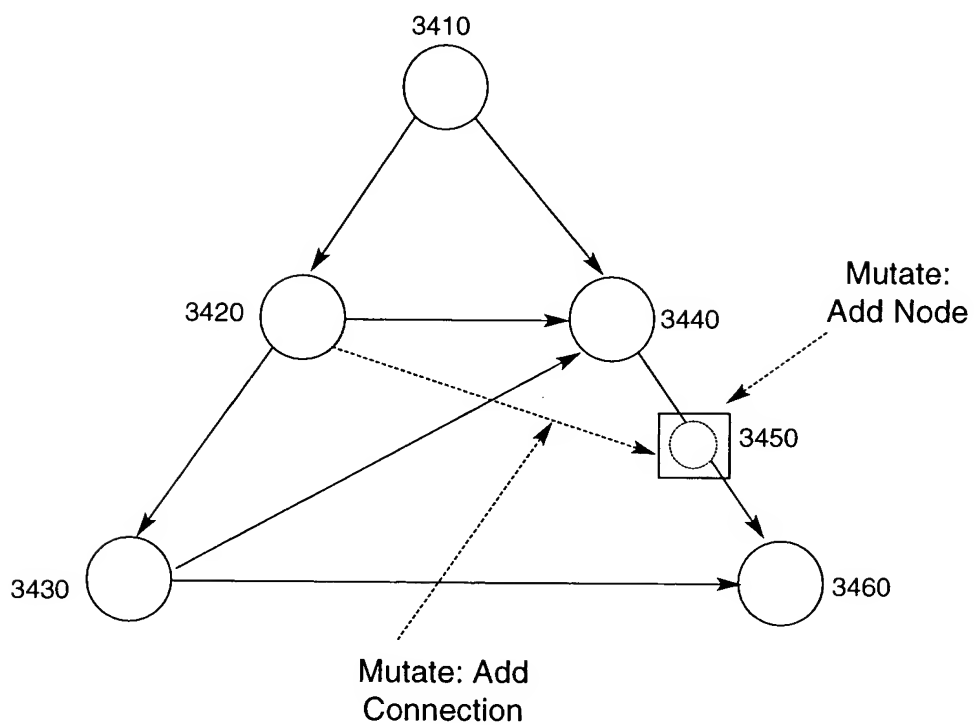
Fig 35: Evolutionary A-NN Non-deterministic Feed Forwarded

(I)

3510

3515   3520   3525

3530   3535

(II)

3540   3545

3550   3555   3560

3570   3575   3580
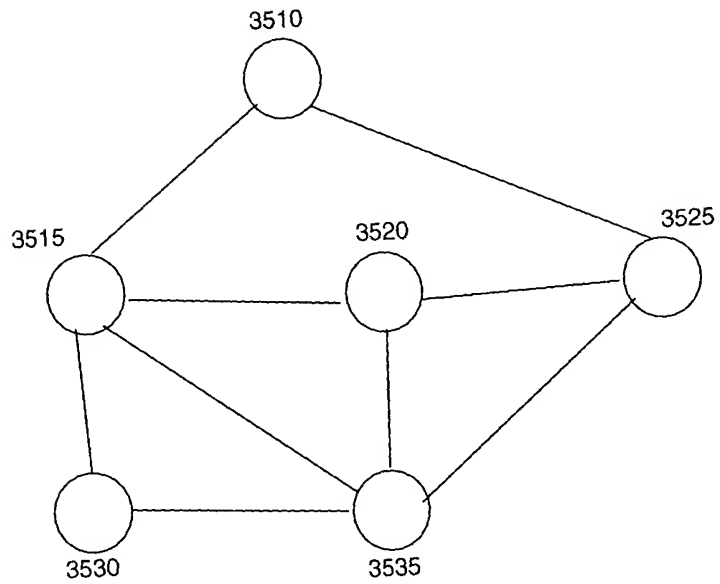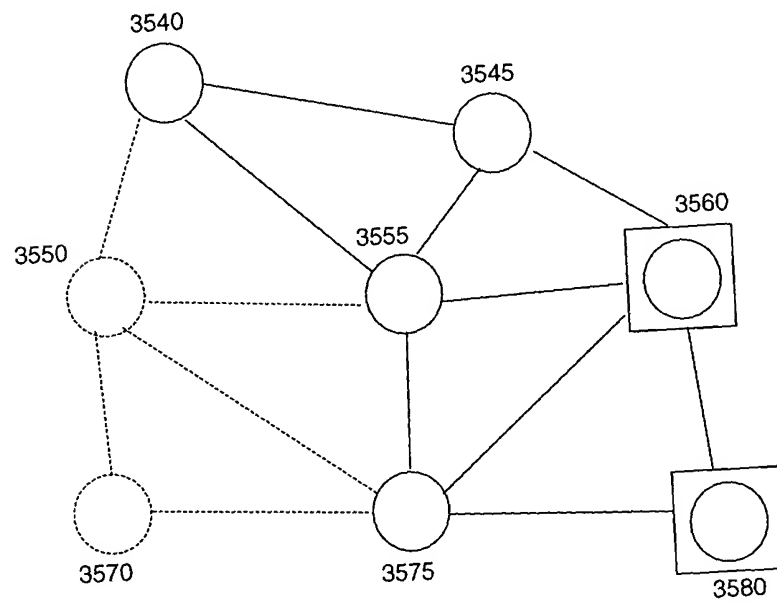
Fig 36: Evolutionary Search For Connection Weights in an ANN

3610

1

3

3630

2

Outputs

3620

3

2

2

Inputs

4

3640

6

5

3650
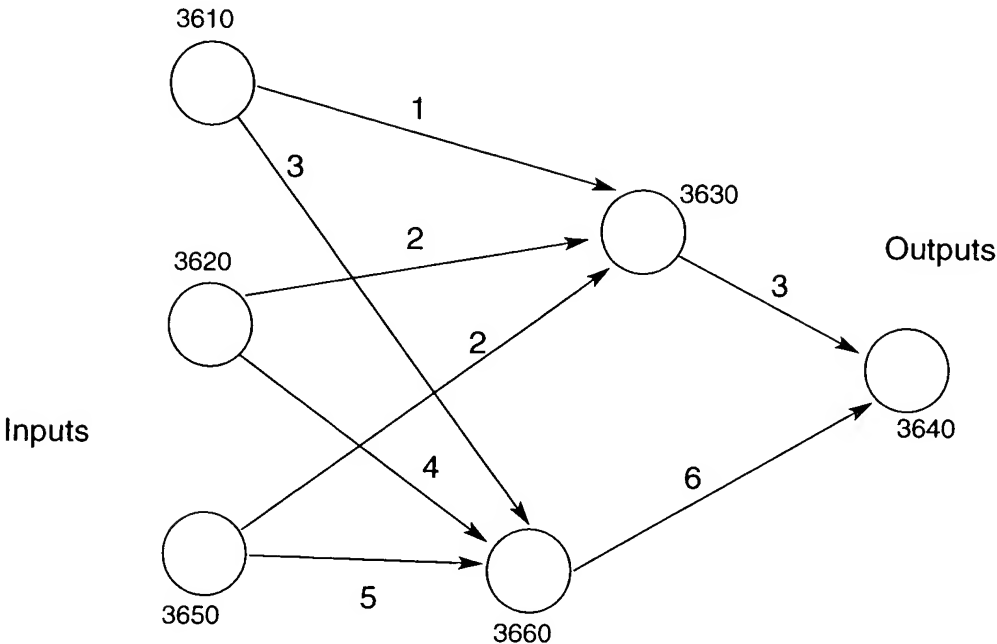
3660

Genotype: 0010 0001 0110 1001 1010

3670

Binary representation of connection weight
chromosome encoding

Fig 37: Fuzzy Logic Module

3710
Sensor provides
crisp
data input

3770
Controlled ran-
dom mutations

3720
Fuzzification of
data in fuzzifier
module

3780
Fuzzy
rules

3730
Fuzzy analysis in
fuzzy inference
engine

3790
Rule
adaptation

3740
Defuzzification of
data in defuzzifier
module

3750
Crisp data
output

3760
Actuators
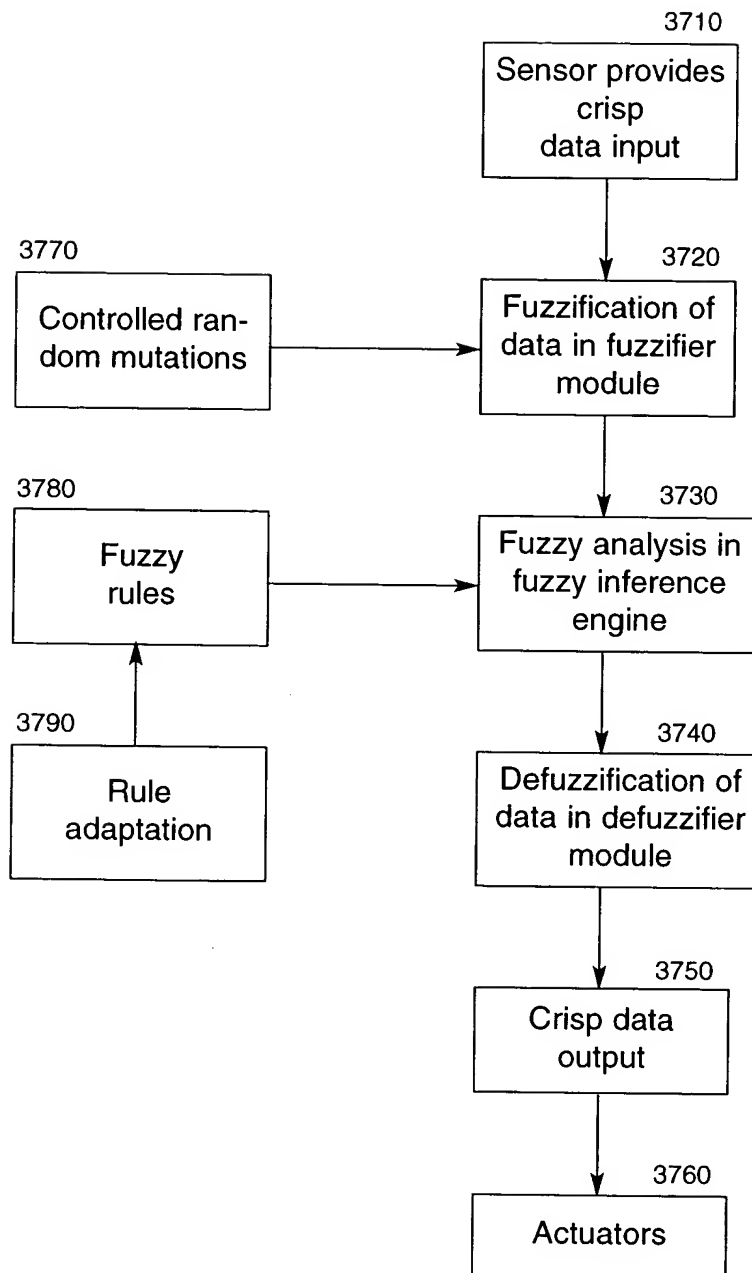
Fig 38: Neuro Fuzzy Controller with Two Input Variables & Three Rules

3810

A1

3820

A2

(Rule
base)

R1

3830

R2

3840

R3

3850

X

3860
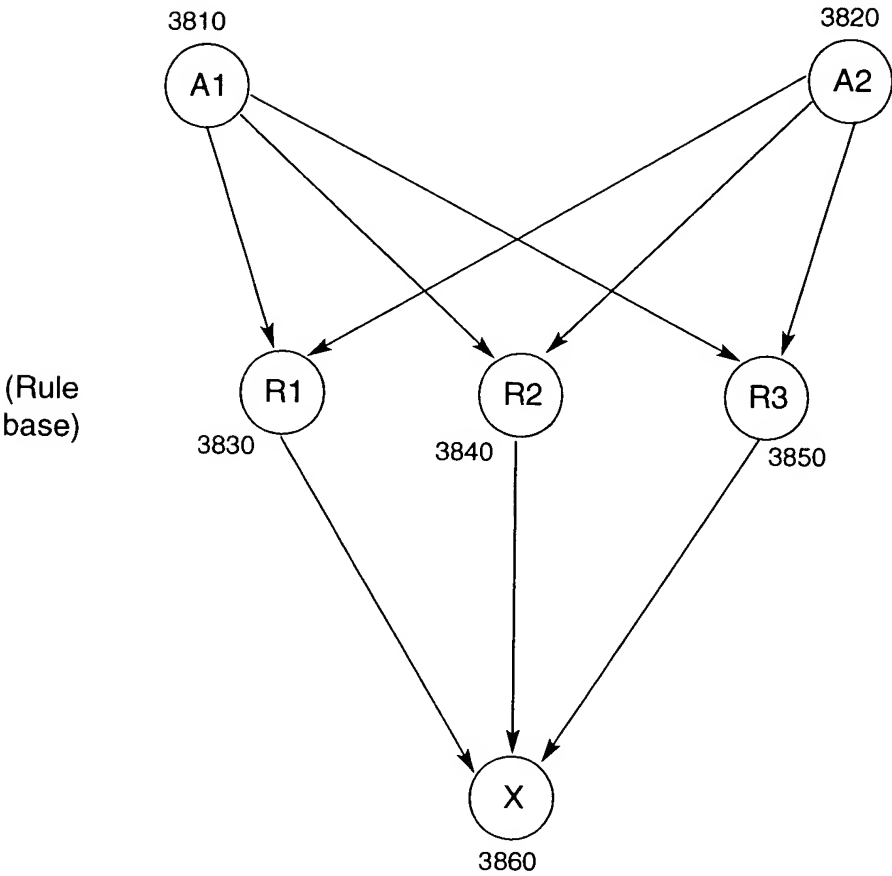
Fig 39: Five Layer Evolving Fuzzy Neural Network

Fuzzification

Decision Layer

3920

3940

3910

Rule Nodes

3930

3950

Inputs

Outputs
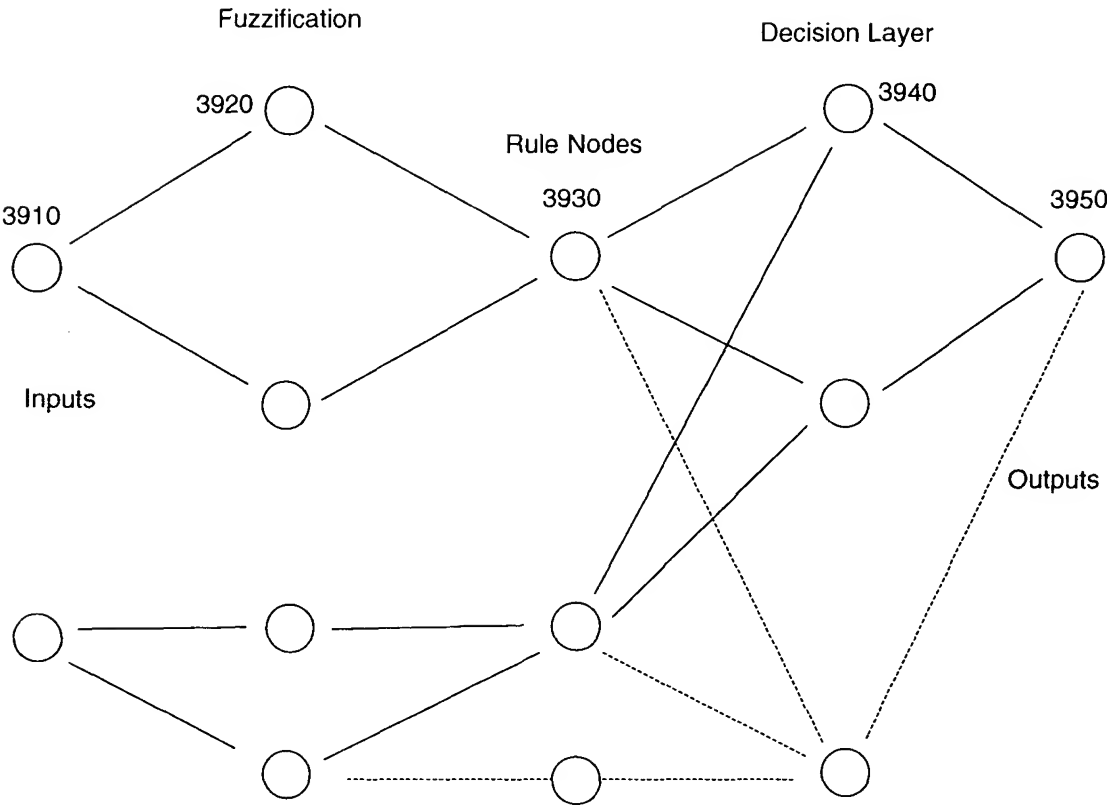
Fig 40: Adaptive Network Based Fuzzy Inference System

Initial parameters

Training process

Consequent parameters

4010

4020

4030

4040

4050

4060

Inputs

Outputs

4070
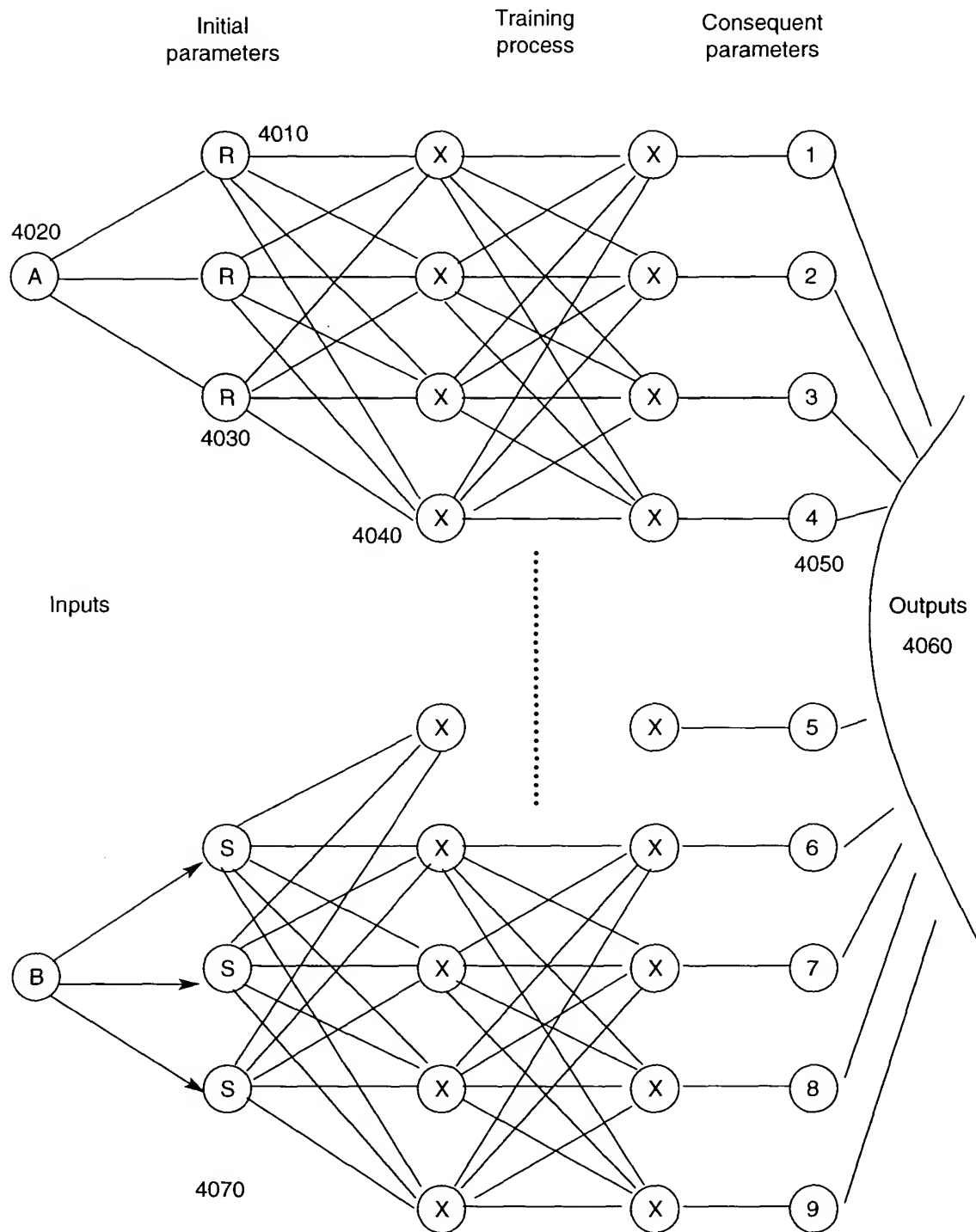
Fig 41: Self Organizing Neural Fuzzy Inference Network Architecture
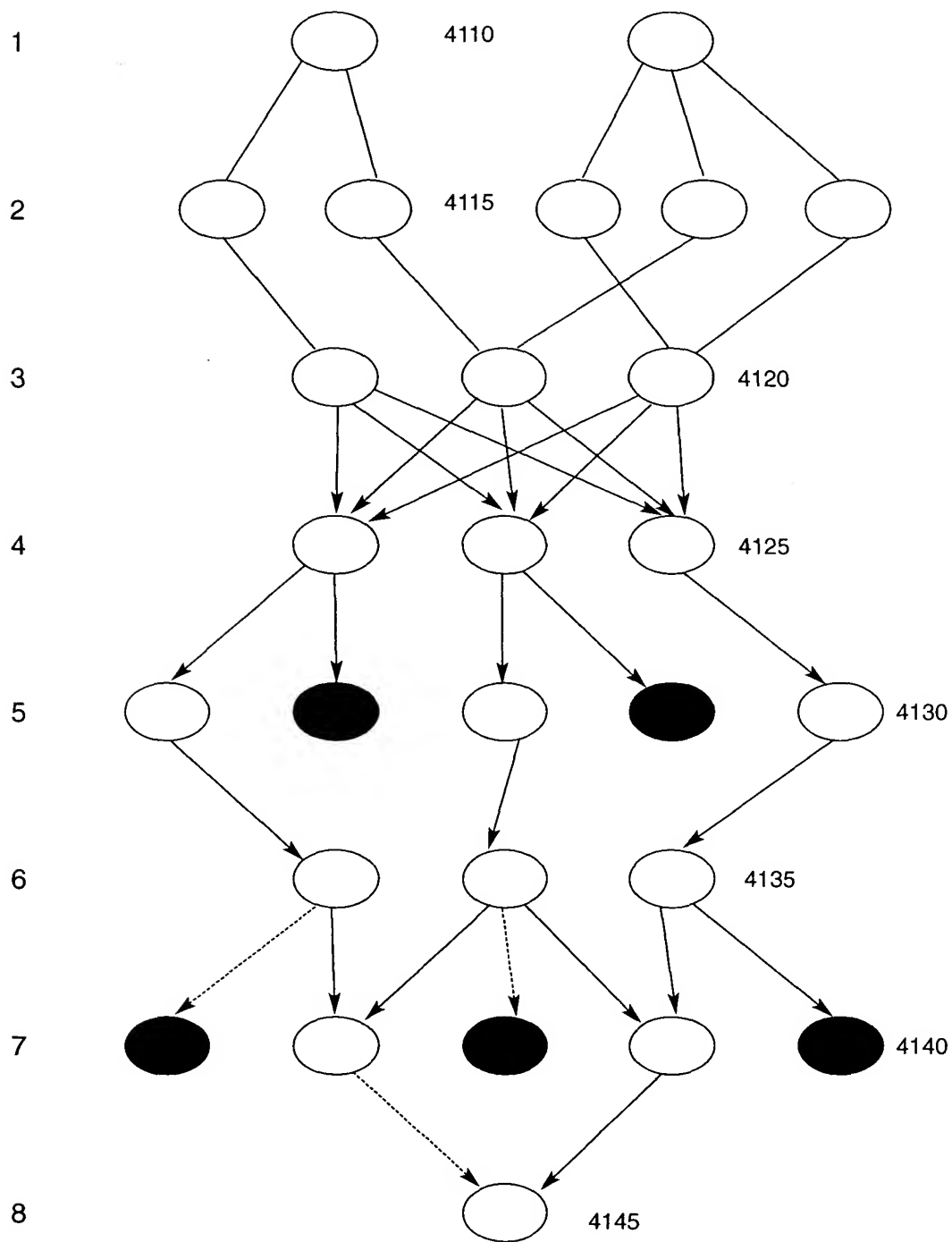
Fig 42: Dynamic Evolving Fuzzy Neural Network

4250   4255   4260   4265   4270

Input
layer

Fuzzy
quantifi-
cation
layer

Evolving
rule
nodes
layer

Weighted
least
square
estimator
layer

Output
layer
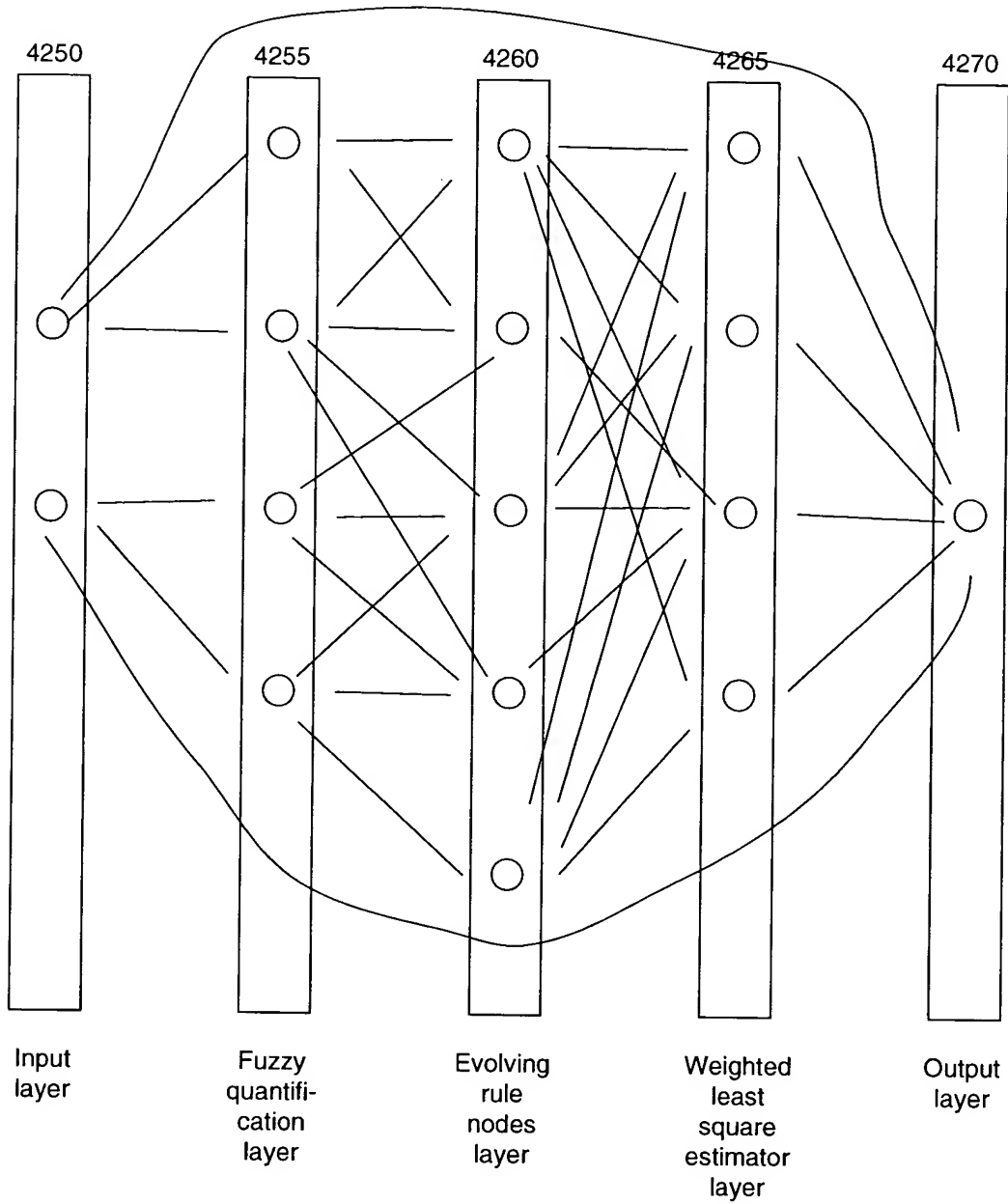
Fig 43: Flexible Extensible Distributed ANN - Shared ANN Computation Between MRAs

4310

4320

Fig 44: IMSA Dynamics in MAS: MRA Interactions via IMSAs

4410

MRA[1]

4420

MRA[2]

Launch
collaboration
agent

Receive
collaboration
agent

Search
agents
launched
to search
databases

Collaboration initiated

MRA[3]

Negotiation via INAs

MRA[4]

4430

4440

Analytical agent
launched

Fig 45: IMSA Relations Between MRAs

Fig 46: Analytical Agents

4610

MRA identifies problem

4620

Generation of analytical agent from MRA

4630

Search agent sent to multiple MRA
databases in initial query

4640

Search agent reports back to MRA the
priorities of data in MRA databases

4650

AA sent to MRA in sequence
(from highest priority to lowest)

4660

AA analyzes problem using specific methods

| Multi-variable Analysis | Regression Analysis | Pattern Analysis | Trend Analysis | Hybrid Analysis |

4670

4680

AA develops solution options to problem

4690

AA shares results with relevant MRA

Fig 47: Search Agents

4710
Generate
search agent

4720
Search agent queries dis-
tributed MRA databases

4730
Search agent receives initial feedback
from databases regarding initial query

4740
Search agent refines query with
specific databases

4750
Search agent evolves
search parameters

4760
Search agent seeks specific
data sets among databases

4770
Search agent finds data
sets as result of refined
search and retrieves them
for the MRA

Fig. 48: Intelligent Negotiation Agents

4810

Initiator INA
Meta-agent
is launched

4820

Initiator INA Micro-
agent 1 launched
for specific negotia-
tion session at INA2
location

4825

Initiator INA Micro-
agent 2 launched for
specific negotiation
session at INA3
location

4830

Initiator INA Micro-
agent 3 launched for
specific negotiation
session at INA4
location

4835

Negotiation ses-
sion at remote
location

4840

Negotiation ses-
sion at remote
location

4845

Negotiation session
at remote location

4850

Initiator INA at home or
remote location

4855

Winner determination
at home location

4860

Mutual agreement:
INA3 & Initiator INA

4865

Close sessions for
INA2 & INA4

4870

End session

Fig 49: IMSA Intercommunication

```
                                    4910
                    ┌──────────────────────┐
                    │      MRA makes       │
                    │      decision        │
                    └──────────────────────┘
                                │
                                ▼            4920
            ┌──────────────────────────────────┐
            │  Content of decision is trans-    │
            │  lated into specific instructions │
            │       of action to take           │
            └──────────────────────────────────┘
                                │
                                ▼            4930
            ┌──────────────────────────────────┐
            │          MRA creates             │
            │       messenger sub-agents       │
            └──────────────────────────────────┘
                                │
                                ▼            4940
            ┌──────────────────────────────────┐
            │     MRA launches messenger       │
            │     sub-agents to other MRAs     │
            └──────────────────────────────────┘
                                │
                                ▼            4950
            ┌──────────────────────────────────┐
            │      Messenger sub-agents        │
            │       deliver message with       │
            │       instructions to MRAs       │
            └──────────────────────────────────┘
```

Fig 50: INA Architecture

5010 INA2

5015 INA3

5020 Initiator INA

5025 INA4

5030 Pre-negotiation session

5040 All INAs Negotiation session 1 between initiator INA and several INAs

5045 INA stops negotiating with INA4

5050 Initiator INA & INA2 & Initiator INA & INA3 session 2

5070 INA stops negotiating with INA2

5060 Initiator INA & INA3 Negotiation session 3

5080 Agreement reached

5090 Close session

Fig. 51: Pre-Negotiation

5110

Initiator INA requests terms of
negotiation session

5120

INA Micro-agent launched

5130

Initiator INA goes to
other locations

5140

S1 first
response

5145

S2 first
response

....

5150

Sn first
response

5160

S(1,2, ...,n) pre-negotiate parameters of interactive session
including location(s), protocols (language, translation, security,
encryption, etc), double auction method, etc

no

yes

5170

Establish rules of negotiations & number of negotia-
tion sessions, based on constraints

5180

Independent multi-lateral 1-to-1 negotiation sessions
between S1, S2, Sn and Initiator INA

To negotiation sessions

Fig. 52: INA Logistics

5210
Initiate Session

5215
Initial agent generation and ID tagging

5220
Agent interaction protocol generation

5225
Translator for various agent based inter-communications

5230
Synchronization of INAs in negotiation sessions → No

5245
Terminate

5235
AA

5240
INAs construct unique negotiation strategies using AI

5250
Agents signalling intentions to negotiate with other agents

5255
INAs send out communication streams to "home", revealing locations, status & plans

5260
Initiator INA & INAs pre-negotiate to set rules for negotiation session

5265
Initiator INA launches micro-agents to negotiate with INAs at diff. locations

5270
INAs negotiate

5275
INAs cease negotiation

5280
Initiator INA & INAs agree

5285
Save INA settings for later relaunch

5290
MRA functions are activated consistent with agreement reached in negotiation

5295
Close Session

Fig. 53A: Negotiation in a Distributed System with Mobility

5310
Initiator INA initiates negotiation session with INA2

5315
INAs identify location possibilities at which to negotiate

5320
INAs specify agreed location at which to negotiate

5323
Initiator INA moves to INA2 location with program code

5326
At INA2 location, INA2 identifies incoming Initiator INA entry after activation & approving security protocol

5330
Agents engage in negotiation task

5333
Agents complete negotiation task

5336
Initiator INA notifies its "home" computer by sending message of activities at remote location

5340
Initiator INA executes more tasks at remote location? — No →

5343
Terminate or return home

Home

Terminate

Yes

5347
Initiator INA assesses next task using internal database and analysis

5350
Initiator INA assesses next location for task

5353
Initiator INA identifies next location for task

Continued on next sheet

Fig. 53B: Negotiation in a Distributed System with Mobility (Continued)

5356

Initiator INA moves to another location by generating a micro-agent

5360

Wait for agent to move its program code

5363

Initiator INA identifies need for AI computation

5367

Initiator INA requests AI computation resources at specified location

5370

Initiator INA identifies AI computation resources available

5373

Initiator INA messages to remote location request for AI computation & specifies computation resources sent to specific location

5377

Initiator INA receives AI at specific negotiation site

5380

Initiator INA tests sufficient AI computation resources at remote location

5385

Complete negotiations at remote location

5390

Agent returns home

Fig 54: Simultaneous Multi-lateral Negotiation Process with Multiple Variables

(I)

1   2 - 1

(II)

3 - 1   1

(III)

3 - 2   1   2 - 2

(IV)

4 - 1   1   2 - 3

(V)

4 - 2   1   5 - 1

(VI)

6 - 1   1   5 - 2

(VII)

6 - 2   1   7 - 1

Fig 55: Multivariate Negotiation Factors

MRA1

X
no
A
no
R
no
Z
no

MRA2

Y
no
B
no
S
no
Z
no

Agreement

Z

Select

MRA3

M
no
U
no
C
no
Z
no

MRA2

N
no
T
no
D
no
Z
no

Agreement

Z

Select
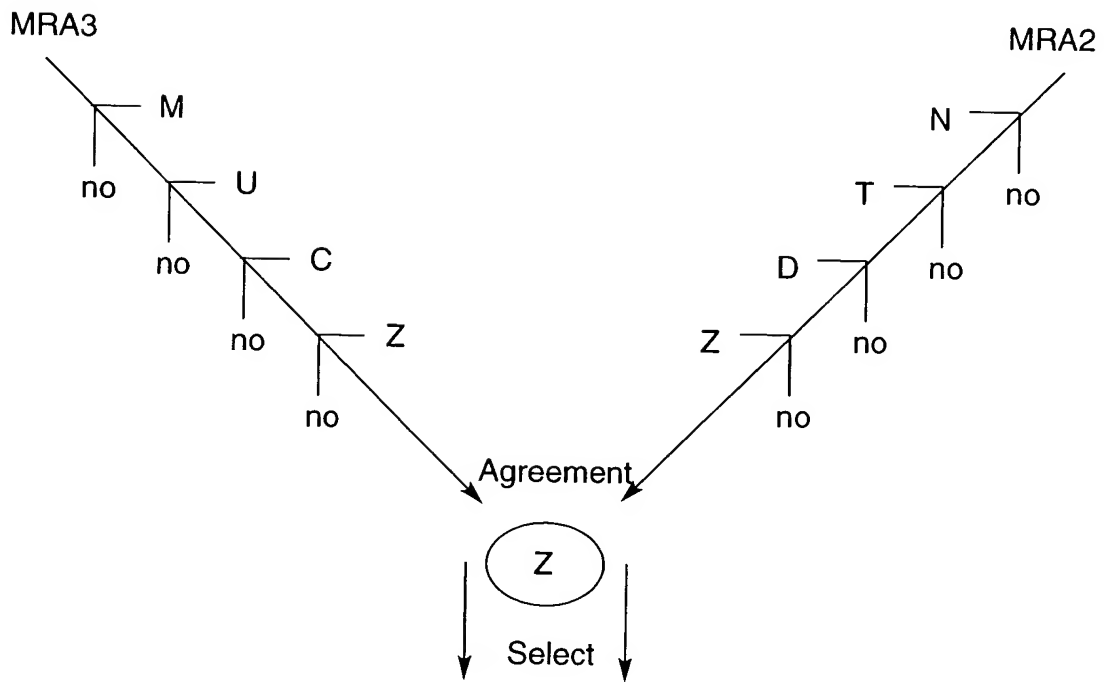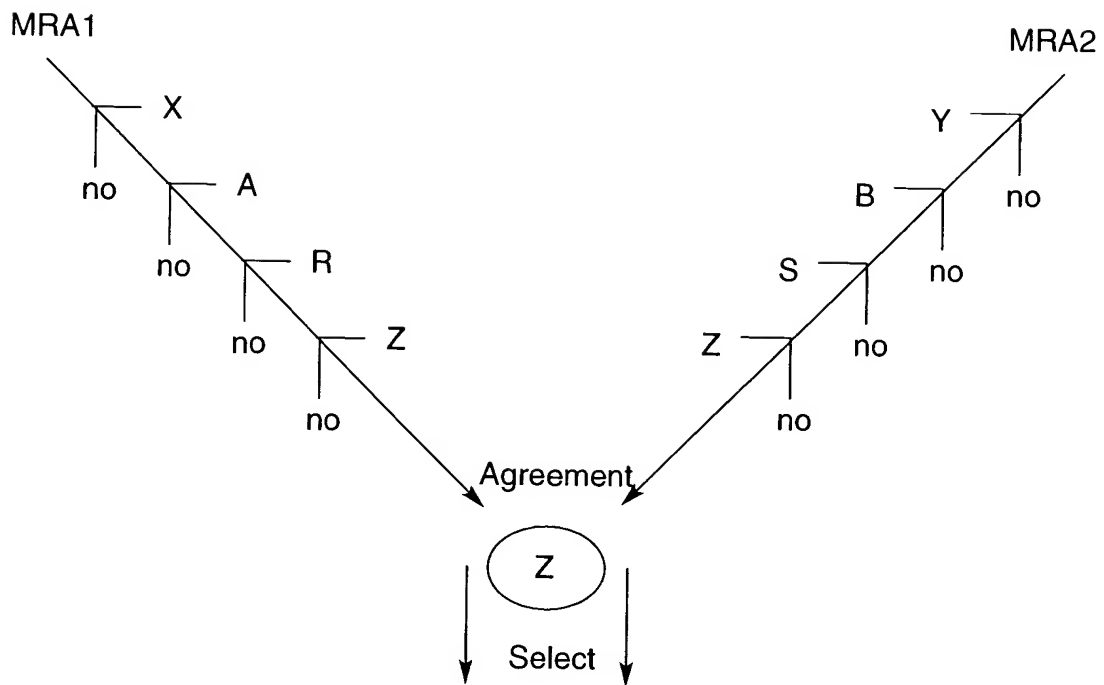
Fig. 56: Winner Determination in Competitive INA Framework

5610 INA-2

5620 INA-3

5630 INA-4

5640 INA-5

Phase I
Need to select
two from field
of at least four

5650 Initiator INA

5660 INA-2

5670 INA-4

Phase II
Selection of
two finalists

5680 Initiator INA

5690 INA-4

Phase III
Selection of
winner
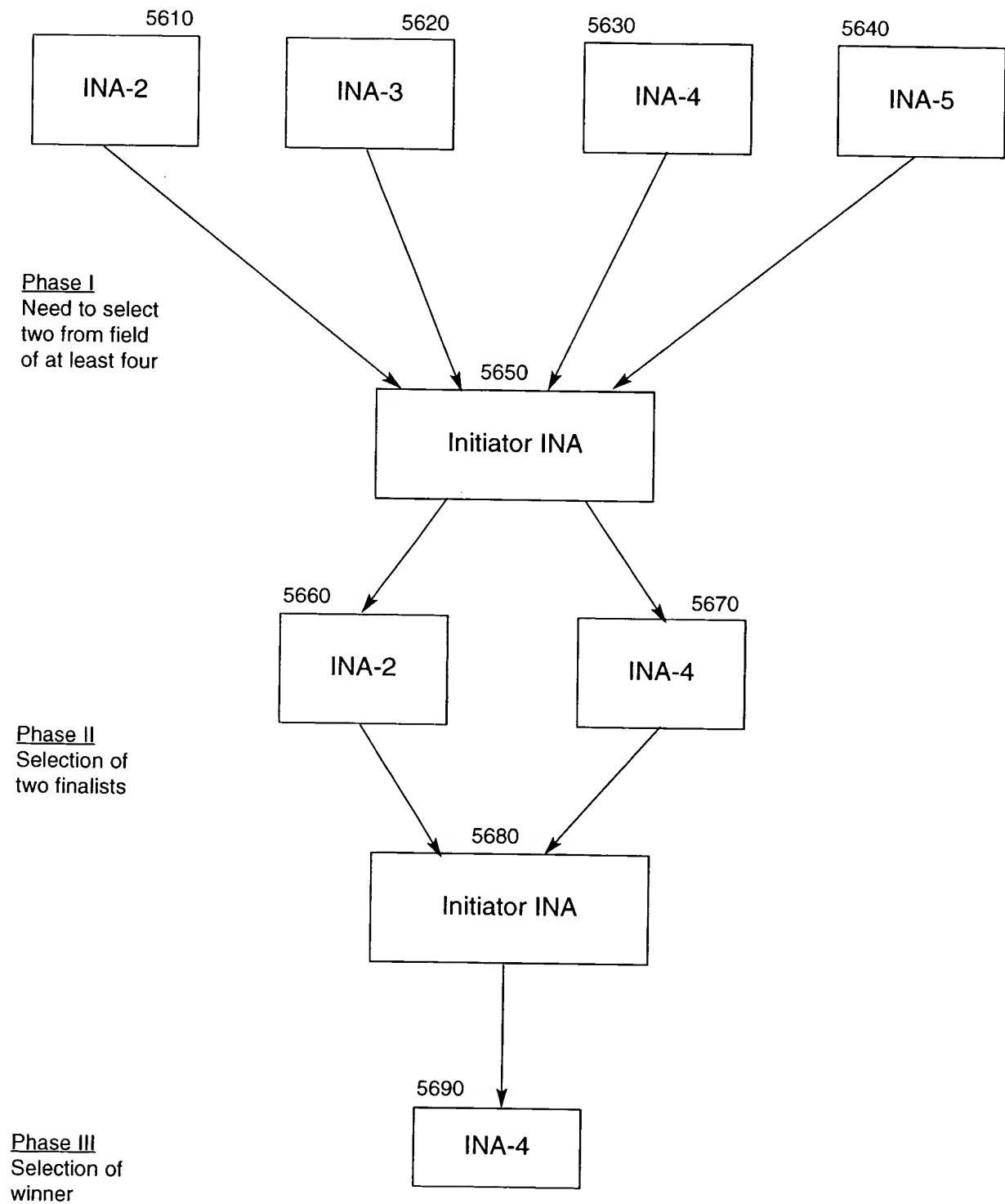
Fig 57: Argumentation Process

Temporal Phases	5710	5720 A	5730 B
Negotiation variables			X
Prune out uncompromise variable		X	
Prune out variables non-negotiable			X
Compromise key variables		X	X

Fig 58: Anticipating Opposing INA Strategies

5810

INA1 presents
argument to INA2

5820

FL, MVA &
regression
analysis

5830

INA2 evaluates
argument

5840

INA2 anticipates INA1
strategy by examining
trajectory of arguments

5850

INA2 seeks to
identify cues to
anticipate behavior
in environment

5860

INA2 presents
counter-argument
to INA1

5870

INA1 anticipates INA2 strategy
by anticipating possible
argument scenarios

5880

INAs reach
agreement

Fig 59: Identify Problems: Group Agrees To Narrow Focus

5910

Any MRA identifies problems

5920

How to carry out a mission with other MRAs → Yes

No

5930

How to combine with other MRAs for a common mission? → Yes

No

5940

How to target an object with a group of MRAs? → Yes

No

5950

Other mission or goal based problems → Yes

5960

Group of MRAs prioritize problems by assigning values to each problem & ordering by rank in real time

5970

Potential solutions requested in order of ranking

Fig 60: Develop Solution Options Between MRAs

6010

Shared 4-D grid created by MRAs to represent framework of potential field

6030

Analyses are performed on specific solution options by MRAs

6040

Simulation scenarios from MRA group are tested in order to detect the best fitting solution for a specific option

6050

Competition is established between various potential solutions for the best solution available

6060

Weights are attached to each solution option

6070

Solution options of simulation scenarios are ranked

Fig 61: Solution Option Selection Method

6110
Develop benchmark of methods to select (simulation scenario)

6150
Environmental changes

6120
Apply experimentation process to test possible solutions

6160
Interact with environment

6125
Shortest path option selected as default without environmental interaction

6170
Receive results of interaction

6130
Prioritize results by weighting for probability of success & by ranking in order of highest probability

6180
Evaluate results of interaction

6135
Refine methods of solution selection

6190
Each MRA has a distinctive vantage in space & time & thus applies a unique risk analysis

6140
Select winner from possible solution options

6145
Optimal solution is selected for a particular scenario

Fig 62: MRAs Select Best Available (not Optimum) Solution To Problem in Present Circumstance While Waiting For Most Recent Relevant Information

6210

MRAs work together to establish list of solution options

6220

Solution options are filtered according to constraints

6230

Time constraints	Optimization con-straints	Combinatorial opti-mization constraints	Accuracy constraints	Quality of information constraints	Pruning what is not probable

6240

MRAs apply solution option methods

6250

Refinement of methods by interacting with environment

6255
convergence of MRA agreement

6260
MRAs partially agree with overlap of interests (within constraints)

6265
MRAs temporarily agree (within constraints)

6270
MRAs do not agree

6275
MRAs select specific simulation scenario solution option

6280
Best available sim-ulation scenario solution option selected

6285
MRAs carry out mission

6290
MRAs carry out mission within constraints

Fig 63: MRA Group Agreement

(A)

Common interest components

MRA1

6310

Argument of 3 sets of common interest overlap

6330

MRA3

MRA2

6320

(B)

Temporal filter

Maximal

6340

Minimal

Most probable "available optimum" scenario within time constraints

Fig 64: Temporal Aspect of Decision Process

6410	6420	6430
Temporal Mode	Physical State	Analytical State
Past	Past experience	Past data flow
Present	Present course of action	Present analysis and decision
Future	Selection of preferred scenario	Future scenarios

Fig 65: Applying Multivariate Analysis to Problem Solving

6510

Problem is forwarded
to MVA filter

6520

MVA filtering process strips variables from problem & analyzes each in isolation

6530

MVA filtering process forwards variable analysis to multiple MRAs

6540

Each MRA analyzes variables & compares with other MRAs

6550

MRAs rank multiple variables & share with other MRAs

6560

Variables of each problem are evaluated in each solution option

6570

Best available solution is selected from solution options

Fig 66: Applying Regression Analysis to Problem Solving of Conflicting MRAs for Winner Determination

6610
Problem is analyzed with regression analysis filter

6620
MRAs sort through various variables of problem

6630
MRAs share data between them

6640
MRAs divide analysis between them

6645
MRAs weight variables by establishing priorities by comparing variable with program parameters

6650
MRAs evaluates importance of variables by comparing with data sets in database

6660
MRAs rank priorities of variables

6670
MRAs apply ranking of problem variables to solution options

6680
MRAs select best solution option by applying program parameters

Fig 67: Applying Pattern Analysis and Trend Analysis to Problem Solving of Conflicting MRAs for Winner Determination

6710
Problem formulated

6720
Pattern analysis required?

6725
Trend analysis required?

6730
Pattern analysis

6735
Trend analysis

6740
Analyze regularities in spatial coordinates using statistical methods

6745
Analyze regularities in temporal coordinates using statistical methods

6750
Evaluate analysis

6760
Rank results

6770
Apply analysis to MRA decision logic

6780
MRA group makes decision & formulates plan

6790
MRA group activates plan

Fig 68: Modeling MRS Activity with Simulations-Situation Assessment

MRAs A, B, C move from place 1 to place 3 in a cubic space

Fig 69: Synchronizing Simulations Within MRA Cluster

6910

MRA sensors
detect other
MRA locations

6920

MRA converts
analogue sensor
data to digital

6930

MRA data about other
MRA positions analyzed
in real time to show
phase state changes

6940

Simulation constructed
to represent data about
MRA position changes

6950

Each MRA continuously
tracks all MRAs in
system in real time

6960

Each MRA constructs
simulation to represent
MRAs in system

Fig 70: Contingency CA Scenario Option Simulations
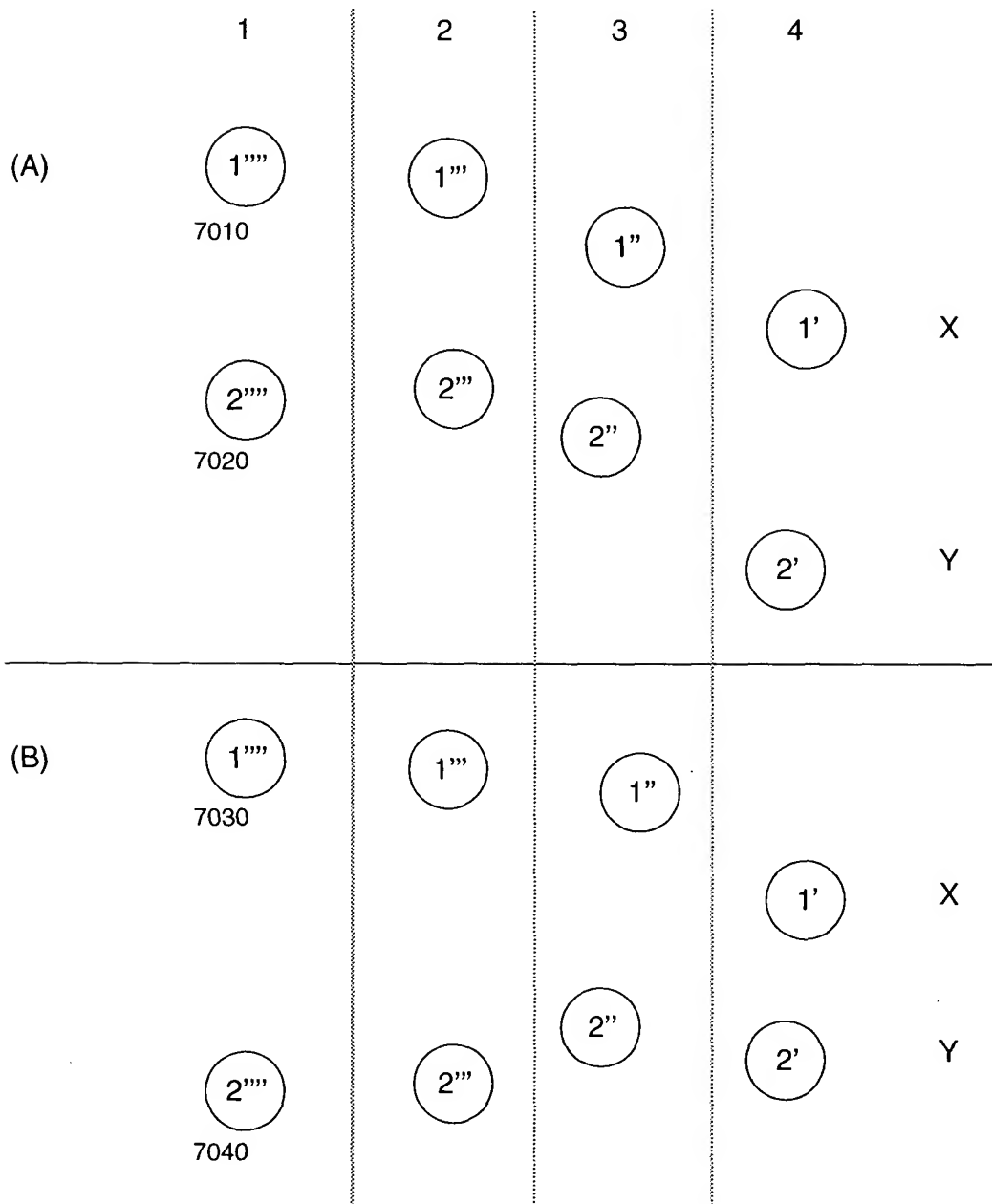
Fig 71: Reversible (Deterministic) CA-Projecting Backwards From A Goal
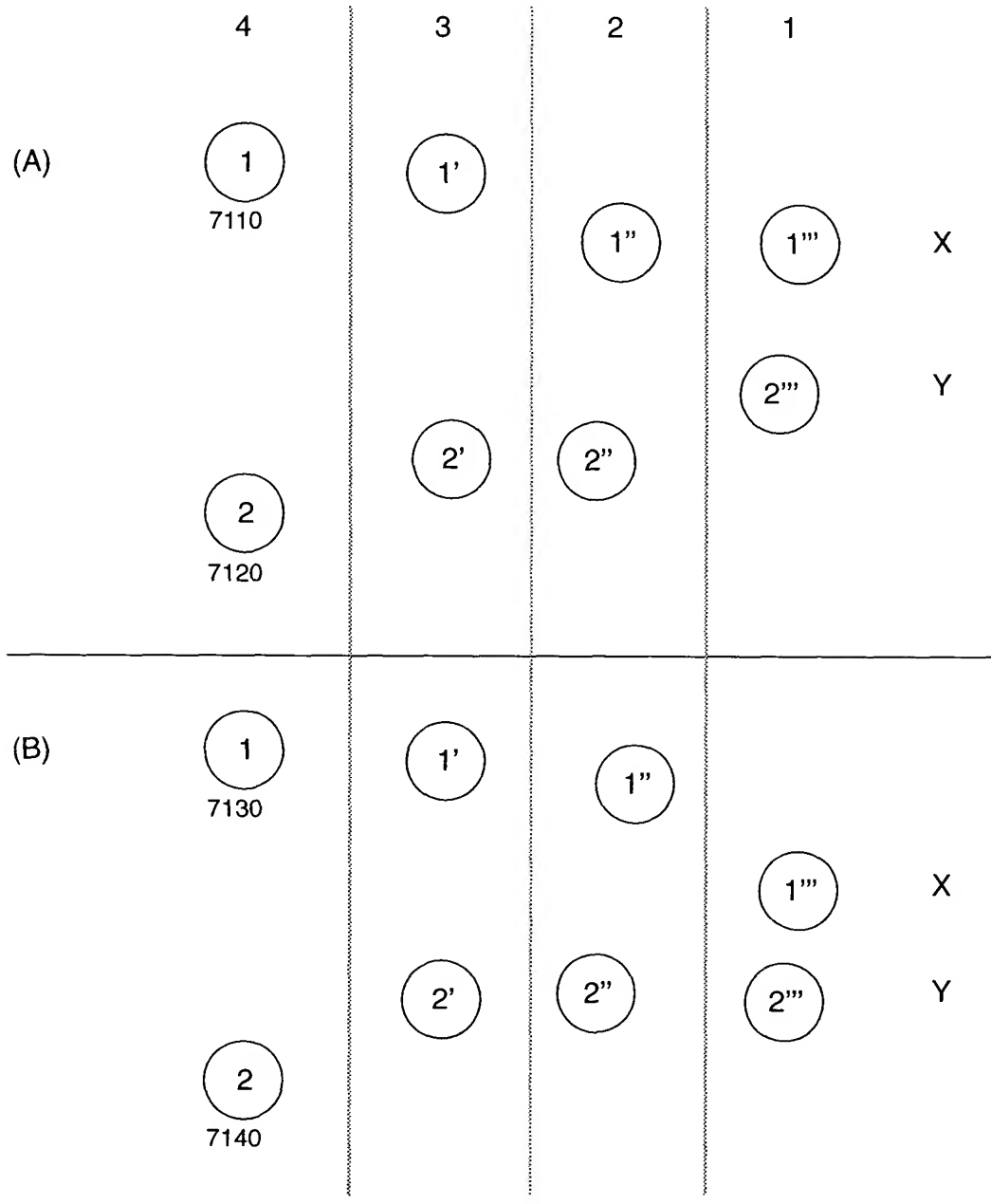
Fig 72: Adaptive Geometric Set Theory Applied To MRS

A

7210

1
2
3

B

7220

1
3
2

C

7230

1
2
3

7240

1
2
3
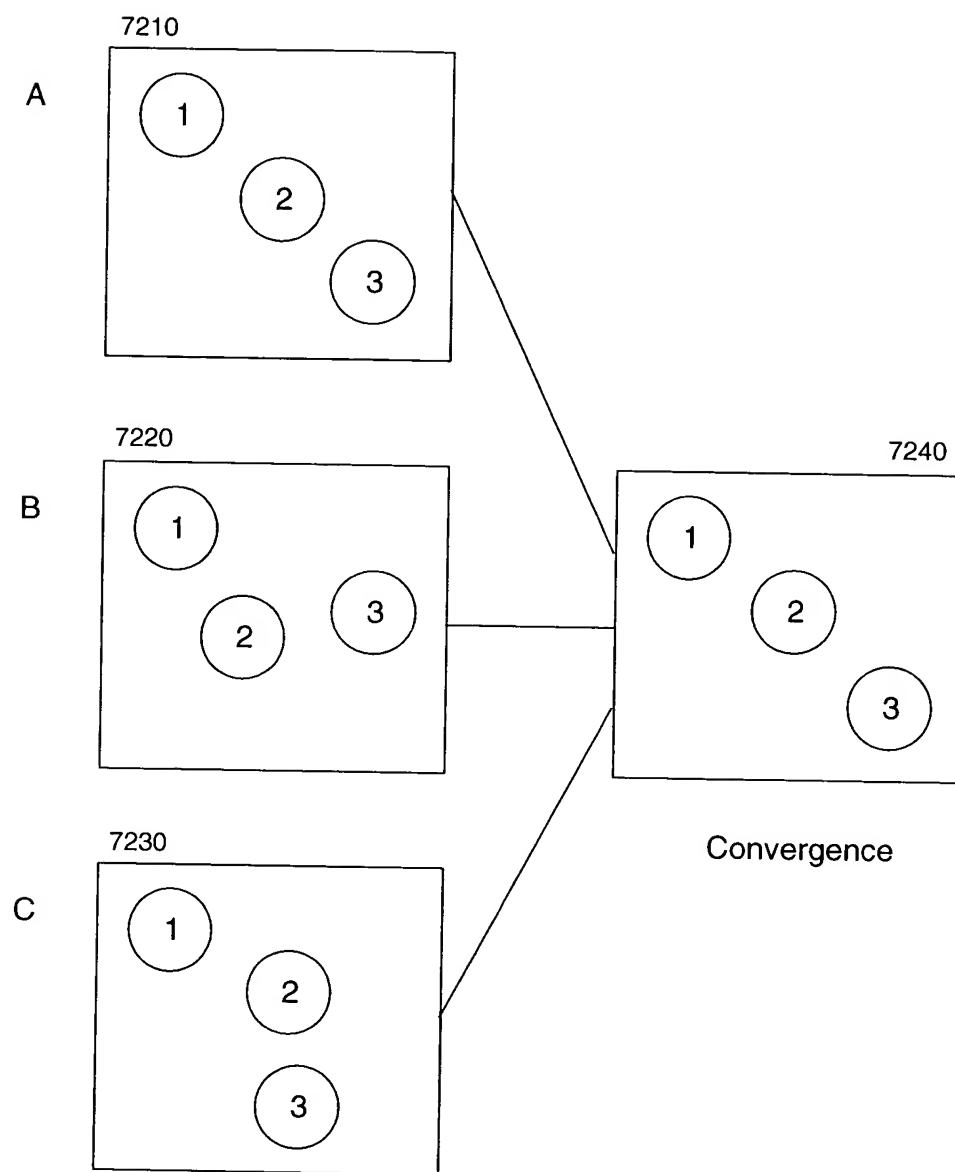
Convergence

Fig 73: Selecting Optimal Simulation-
(Temporary) Convergence of Simulation Scenarios

1R"

1R'"

1R""   7310

1'   1"   1'"   1""   7320   7325

2'   2"   2'"   2""   7330   7335

2R"   2R'"   2R""   7340
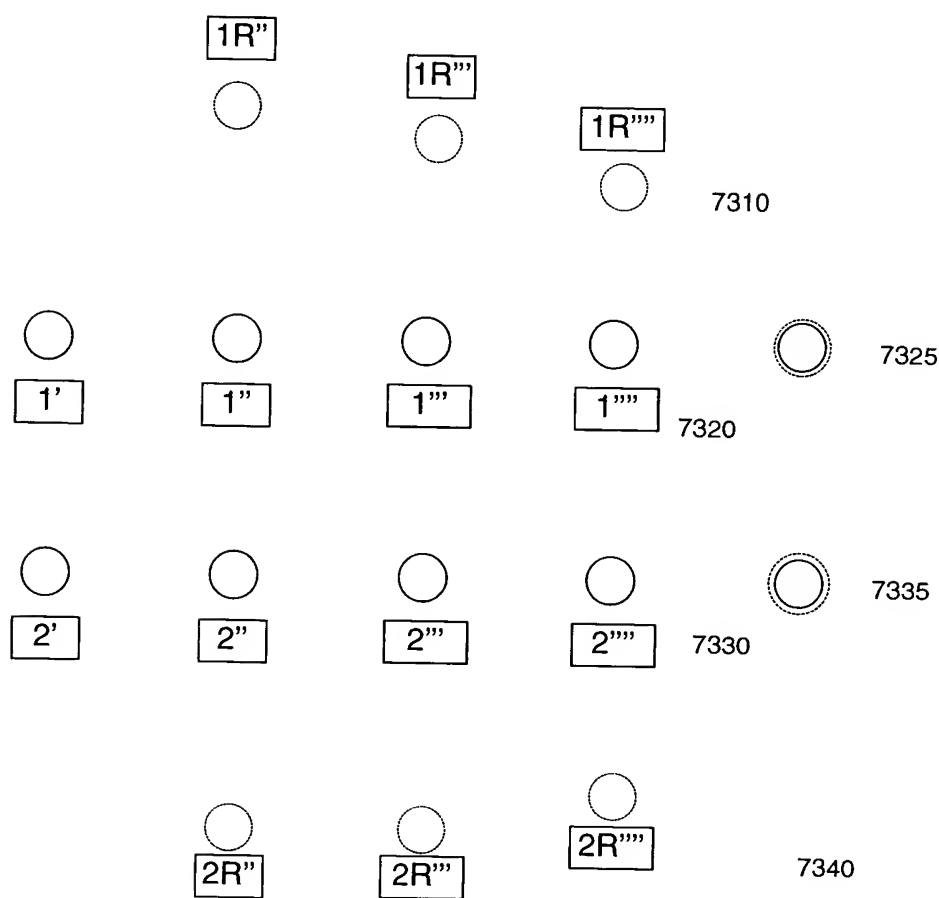
Fig 74: Initiation of Aggregation Process -
Sets of MRAs Forming From Larger Collective

7410
Present simulations

7415
Test simulations using best methods

7420
Prune out least best simulations

7425
Compare best simulations with environment

7430
Compare best simulations with (update) program parameters

7435
Select best simulations (within constraints)

7450
Converge best simulations to create overlap

7455
Create map with converged simulation

7460
Identify MRA location relative to map

7465
MRAs move their physical locations in a geodesic path to mapped location of converged simulation

Fig 75: Initiating Homogeneous MRA Group Formation

I   7510 (X)

7520

II   7530 (X)

7540
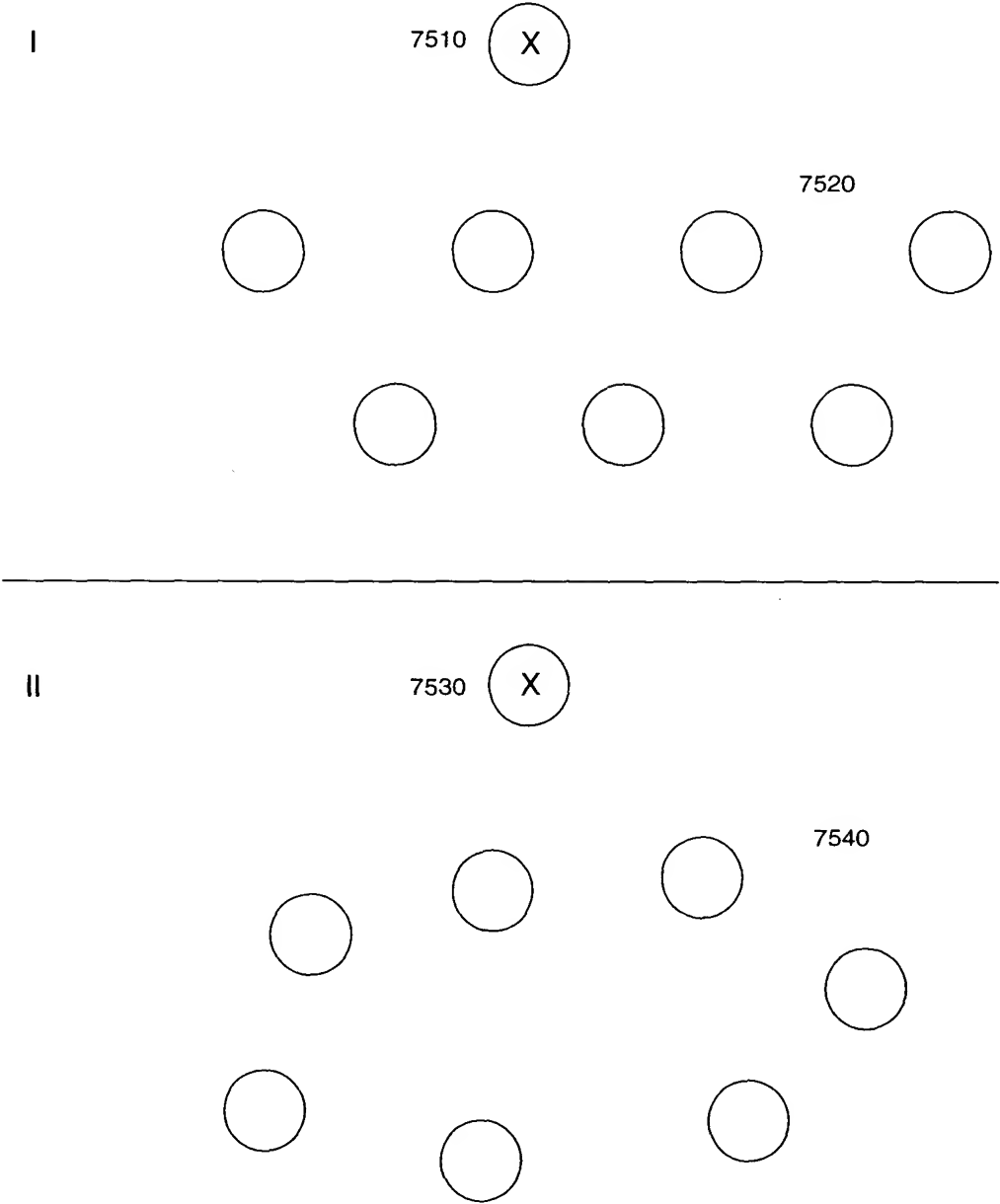
Fig 76: Initiating Common Heterogeneous MRA Group Formation

I

7610 (S)

7620

(S)   (Y)   (X)   (R)

(X)   (T)   (S)   (R)

II

7630 (S)

(S)

(S)

(Y)   (X)   (R) 7640

(X)   (T)   (R)
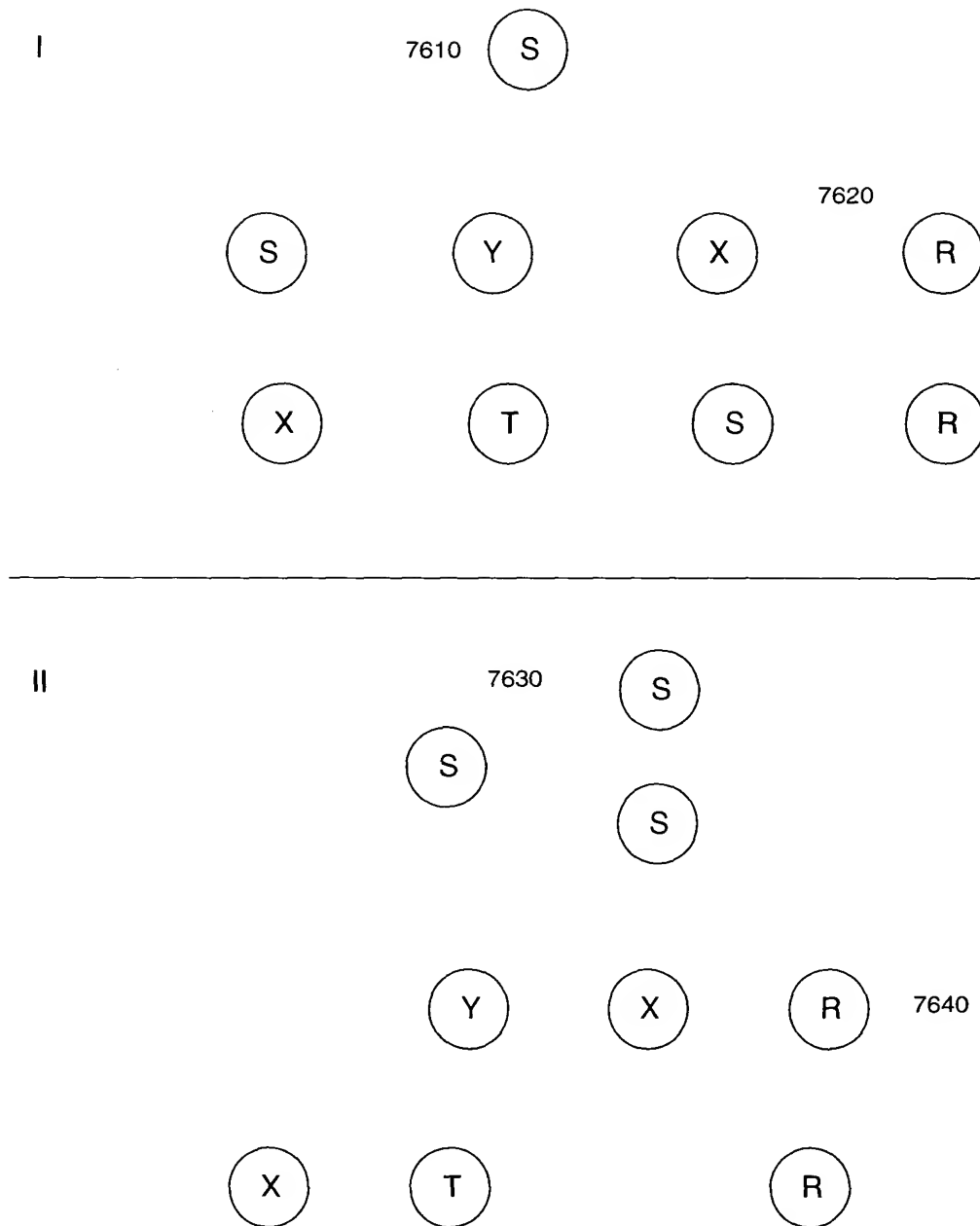
Fig 77: Initiating Complementary Heterogeneous (Specialized) MRA Group Formation

I

7710 (S)

(S) (Y) (X) 7720 (R)

(X) (T) (S) (R)

II

7730 (V) (S) (T)

(S) (X) (R) 7740

(X) (S) (R)
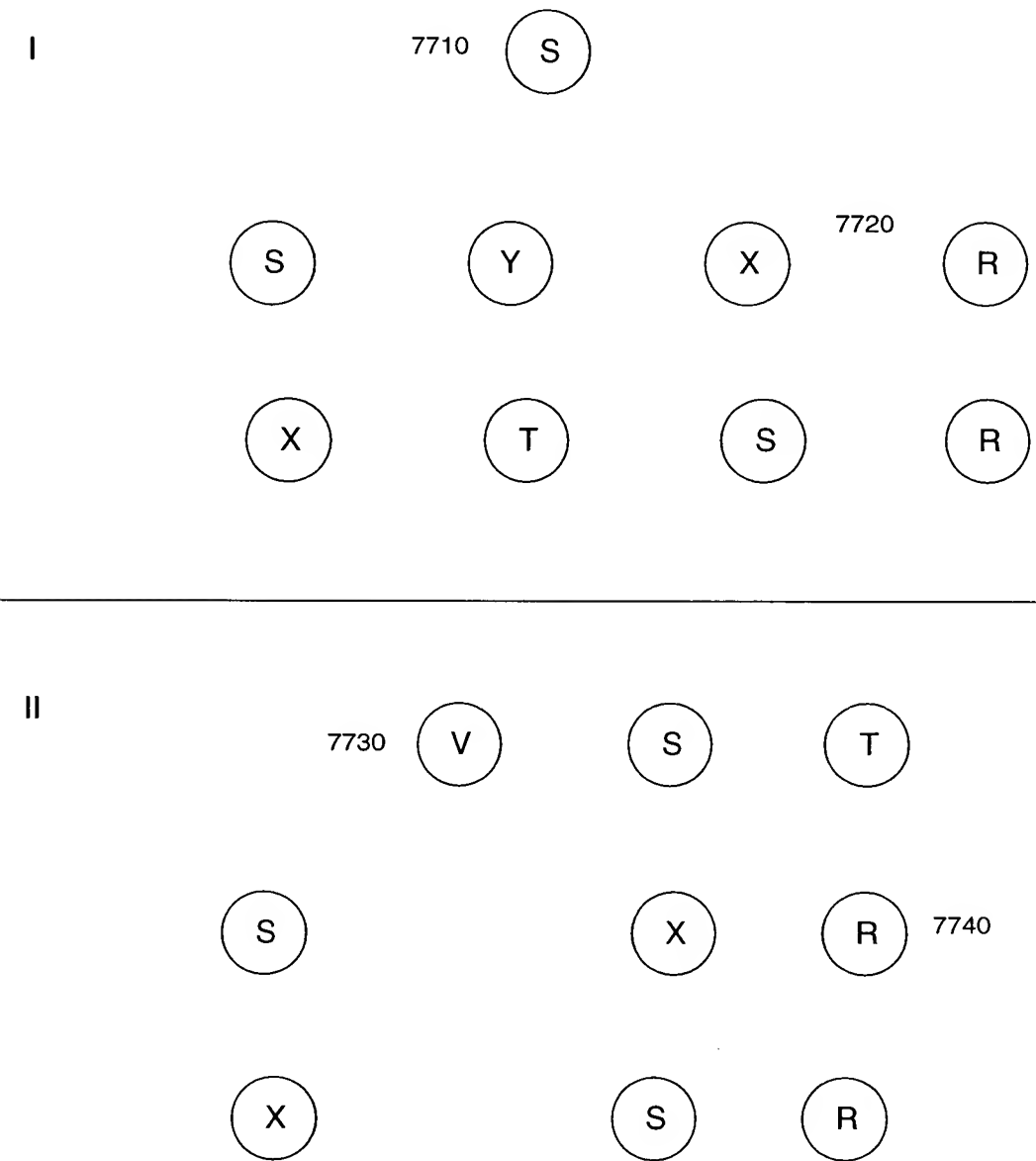
Fig 78: Demand Initiated Environmental Adaptation: Initial Phase

7810
Learning

7820
Environmental changes

7830
Static environment data maps

7825
Dynamic environment data maps

7840
Analysis (MVA)

7850
Past/present simulation

7855
Negotiation between MRAs

7860
Scenario simulation

7865
Decision with limits

7870
Convergence within limits

7875
Choice of specific form of aggregation

7880
Change of spatial positions
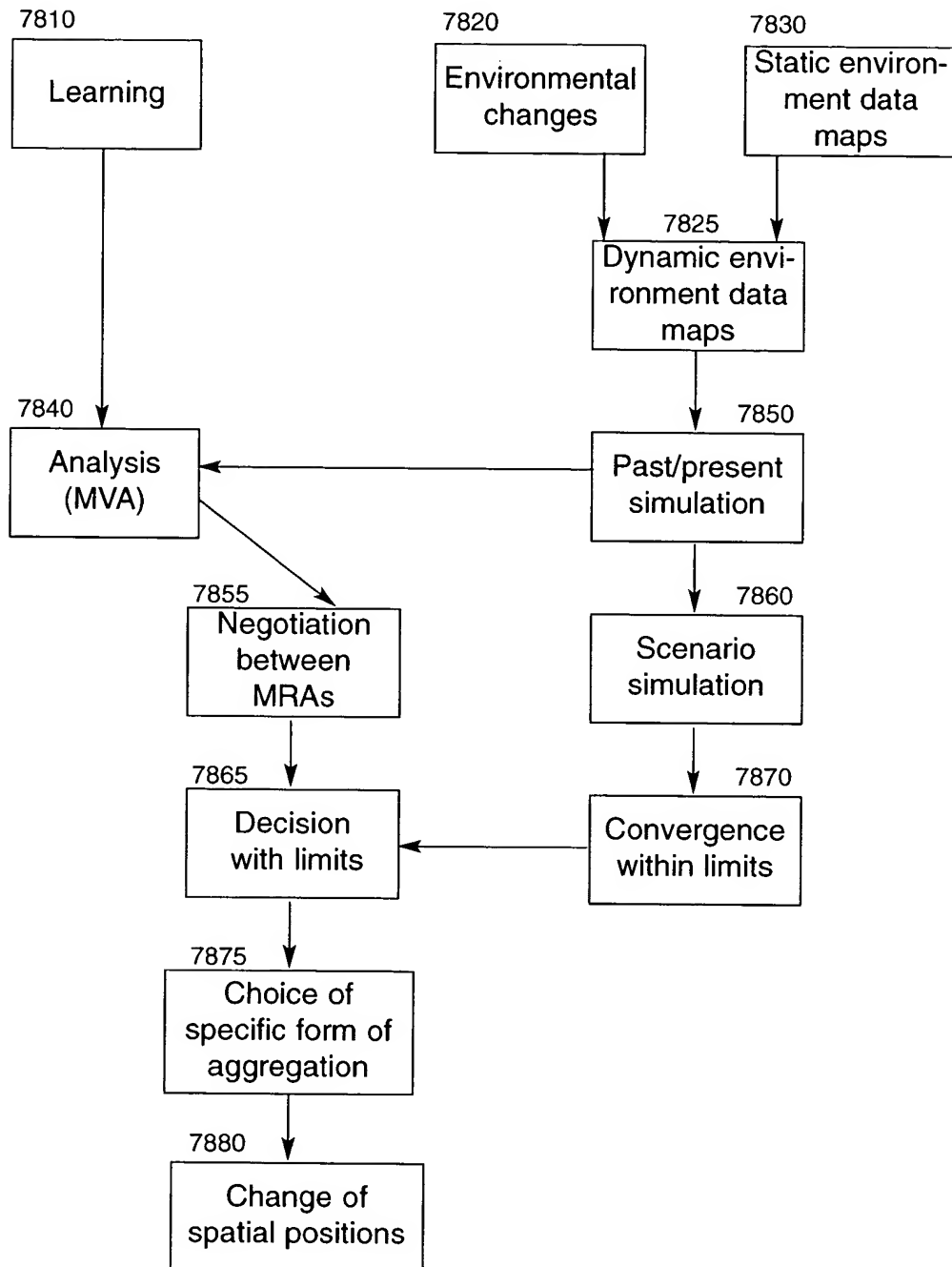
Fig 79: Continuous MRA Group Composition Reconfiguration
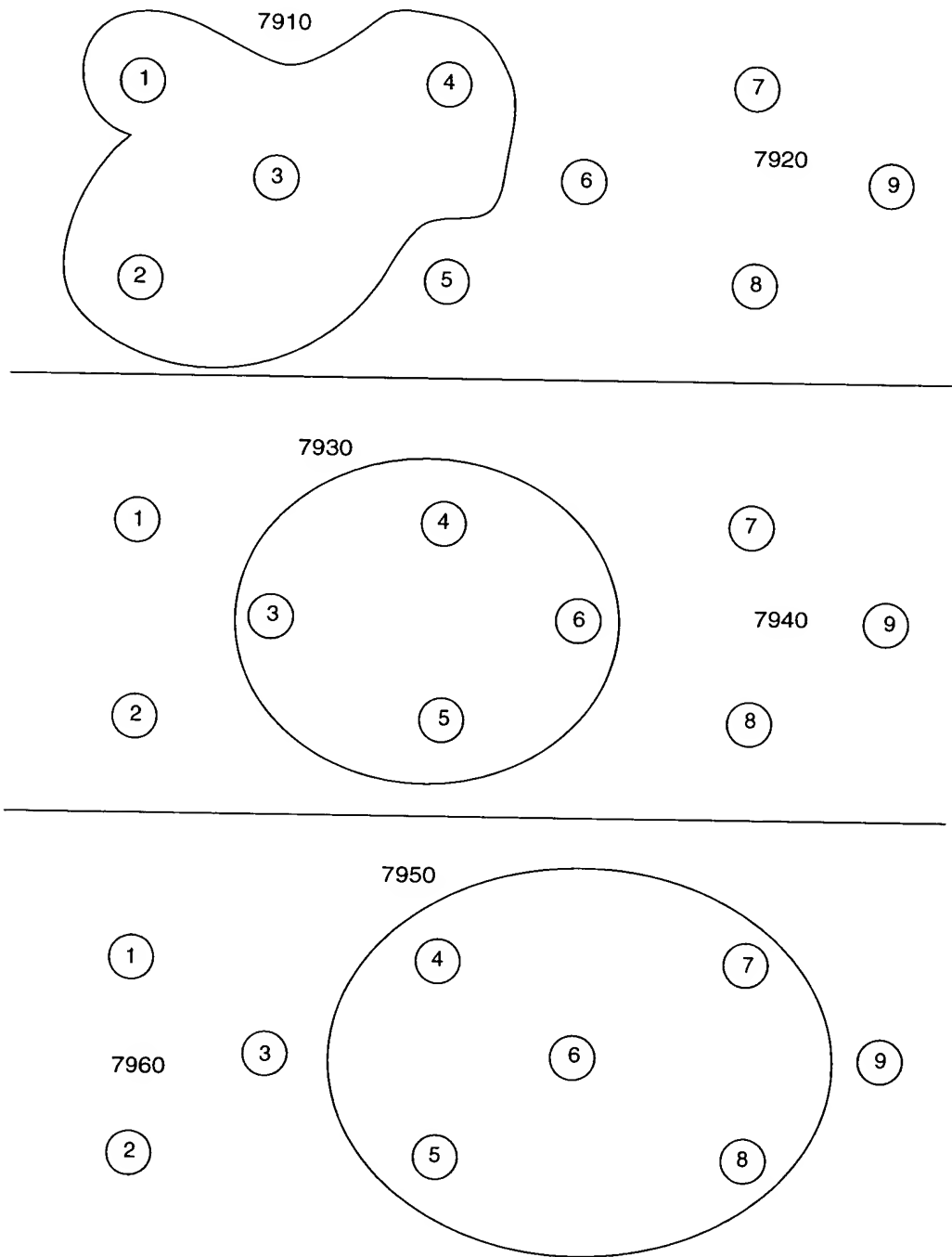
Fig 80: Continuous Reconfiguration of Sub-networks
(Scalable Capacity Increases and Decreases)

(II)   (I)

8010   8005

8015

8020

8025

8030
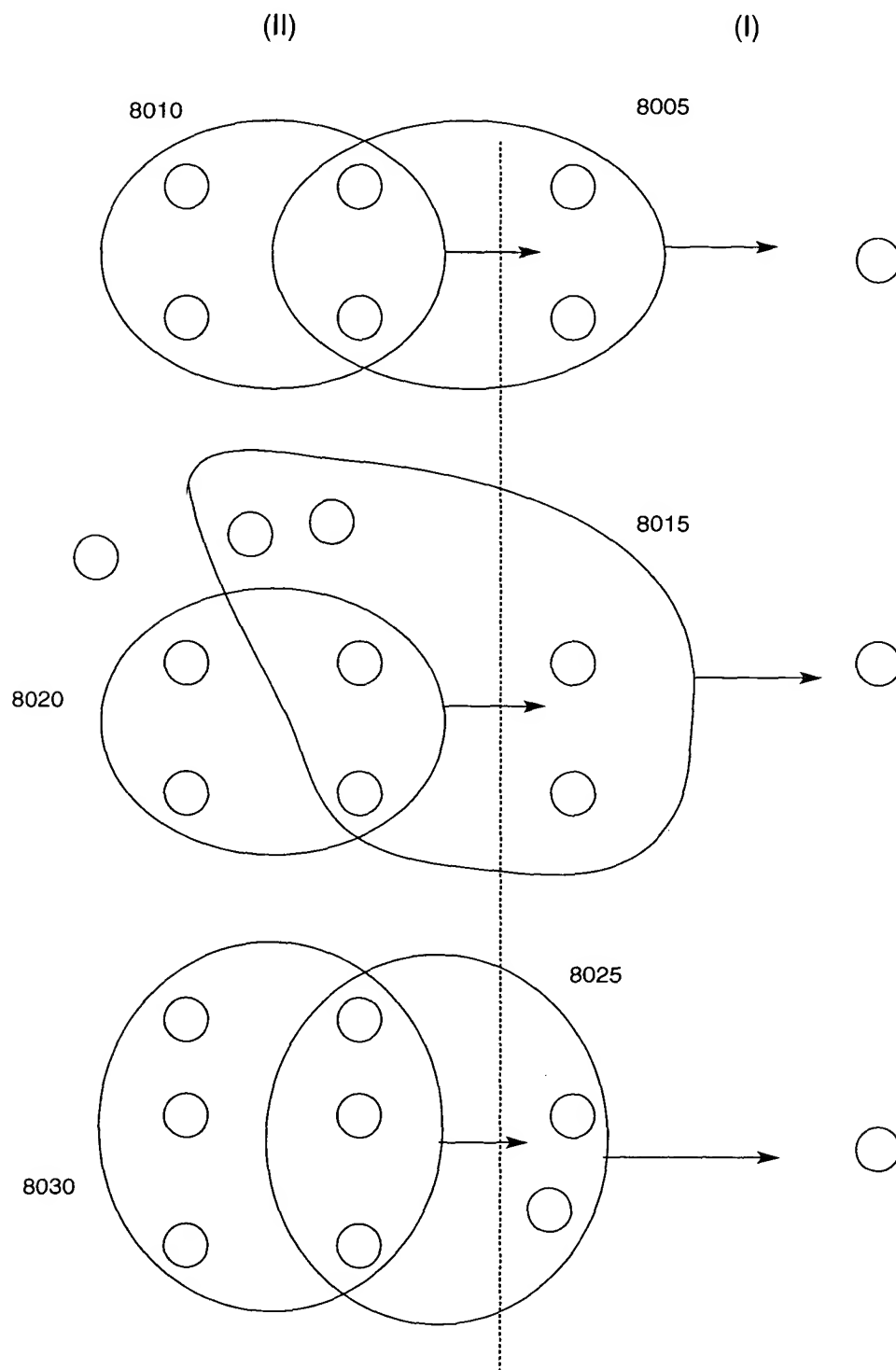
Fig 81: Dynamic Group Behavior Adaptation to Environmental Interaction

8110

8120

8130

8150

8160

8140

8170

8180
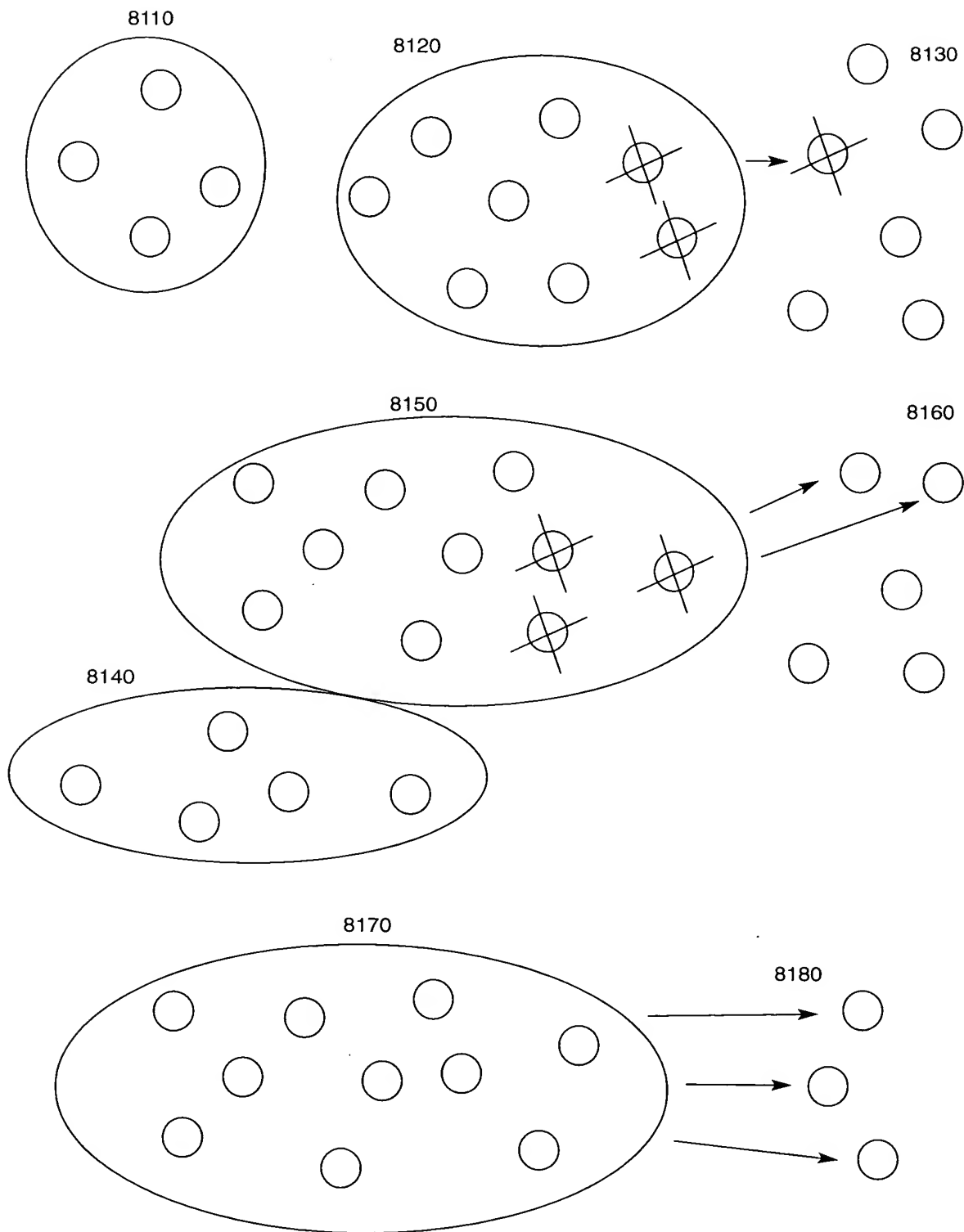
Fig 82: Parallel Dynamic Traveling Salesman with Cooperating Autonomous Agents

8210

MRAs receive sensor data stream

8240

Group of MRAs collect environmental data by sharing sensor data

8250

MRAs use initial prioritization of environmental data consistent with program parameters

8220

Interaction between environment and MRAs

8270

Environmental data changes

8230

Reprioritize program parameters of MRAs

8260

MRAs prioritize order of physical sequence

8280

Reprioritize order of priorities with latest information of changing environment

8290

MRAs perform physical sequence of actions in order of priority

Fig 83: Sacrificing (Altruistic) MRAs in Order to Acquire Sensor Information to Increase Chances of Overall Mission Success

8310

8320
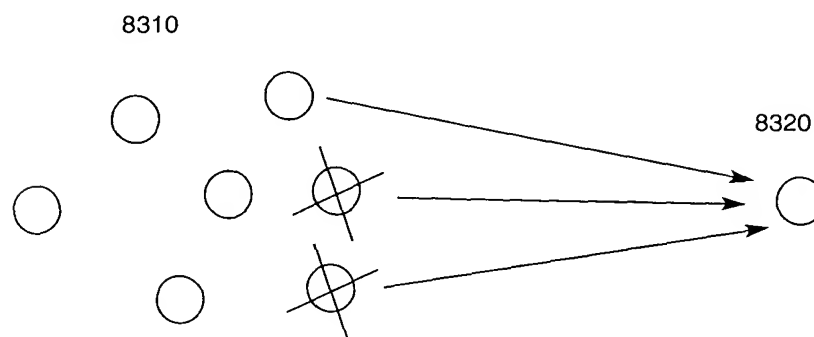
Fig 84: General Dynamic Coalition Process

8455

Mission goals & parameters established

8460

Sensor data & various sources examine terrain

8465

Computation by numerous agents by sharing data and by dividing computation resources

8470

Sensor data evaluated by various robotic agents

8475

Groups emerge by agreeing to congregate

8480

Decisions made to form squads to meet evolving mission parameters and priorities

8485

Specified MRAs update navigation (plans/trajectories) and go to action/attack modes

8490

As mission evolves, squads add or remove members if more members needed, e.g. if opposition is hostile

Fig 85: Group Coordination and Obstacle Avoidance

Obstacles

8510 (X')   (Y')   (Z')

8520

8530

8540

8550 (A')   (B')   (C')
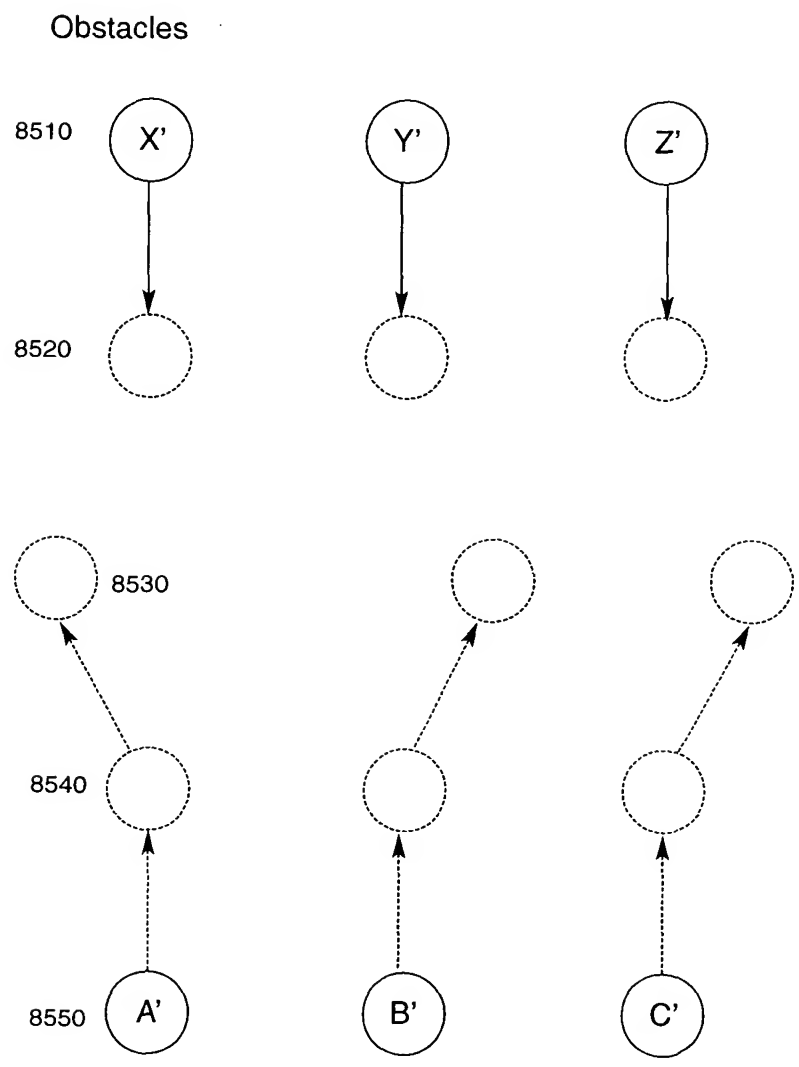
Fig 86: Specialization: Specific MRA Functionality

MRAs

Objects

8610 (A) ----> ◯   (X) 8620

8630 (B) ----> ◯   (Y) 8640

8650 (C) ----> ◯   (Z) 8660
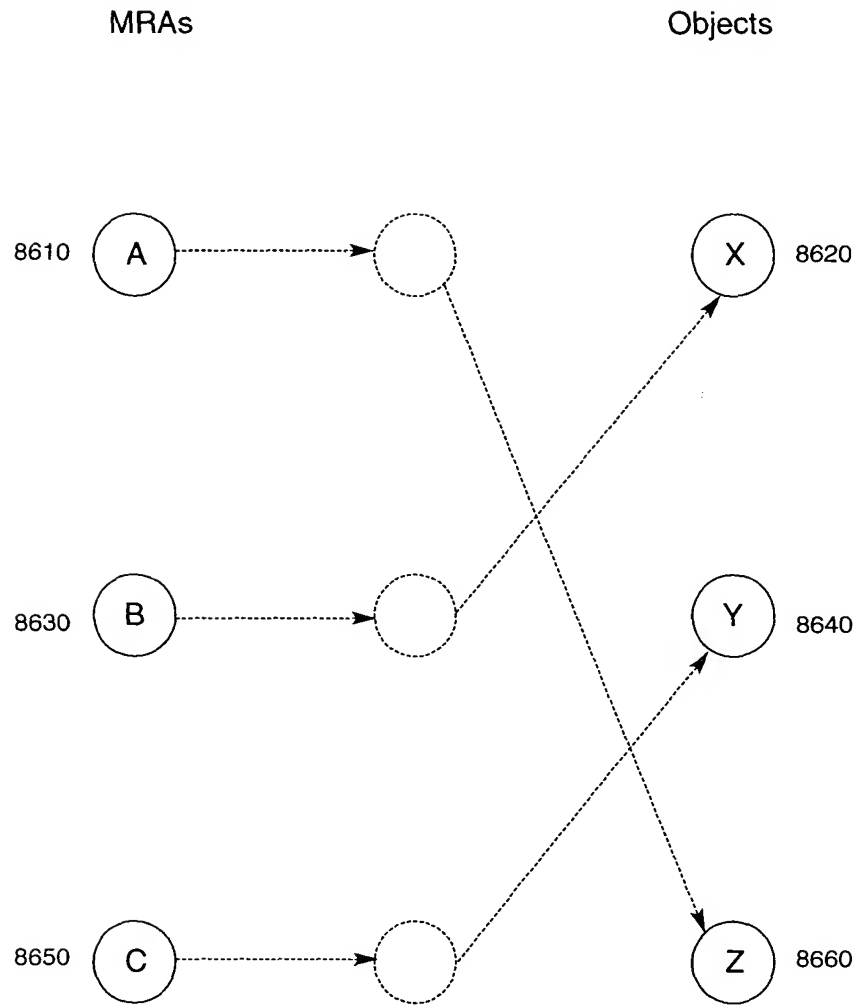
Fig 87: Specialized MRAs Working As A Team
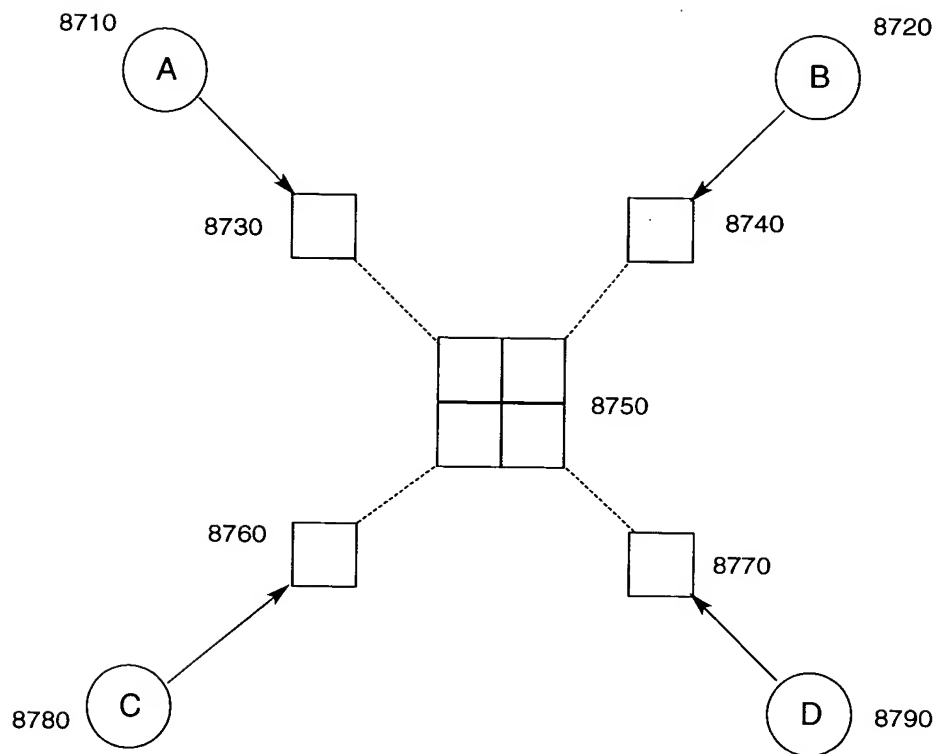
Fig 88: Multi-functional MRAs in Self Organizing Process

8810

A^1

8820

A^2

8830

X

8840

B^2

8850

B^1

8860

Mode two with different speciality function
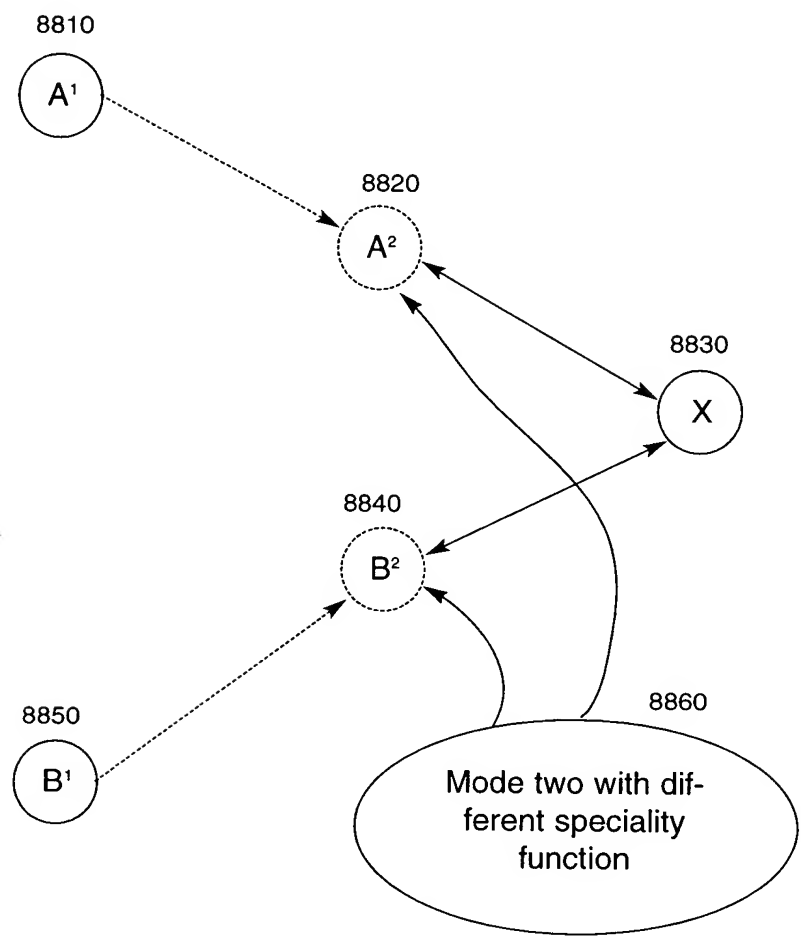
Fig 89: Surveillance & Reconnaissance - Mobile Object Sensed & Tracked By Multiple Micro-MRAs

MRA

MRA

8910 (X)

(Y) 8960

8940   Object

8920 (X2) - - - - - (A) ◄ - - - - (Y2) 8970

8930 (X3) - - - - - (A2) ◄ - - - - (Y3) 8980

8950

8935 (X4) - - - - - (A3) ◄ - - - - (Y4) 8990

8955
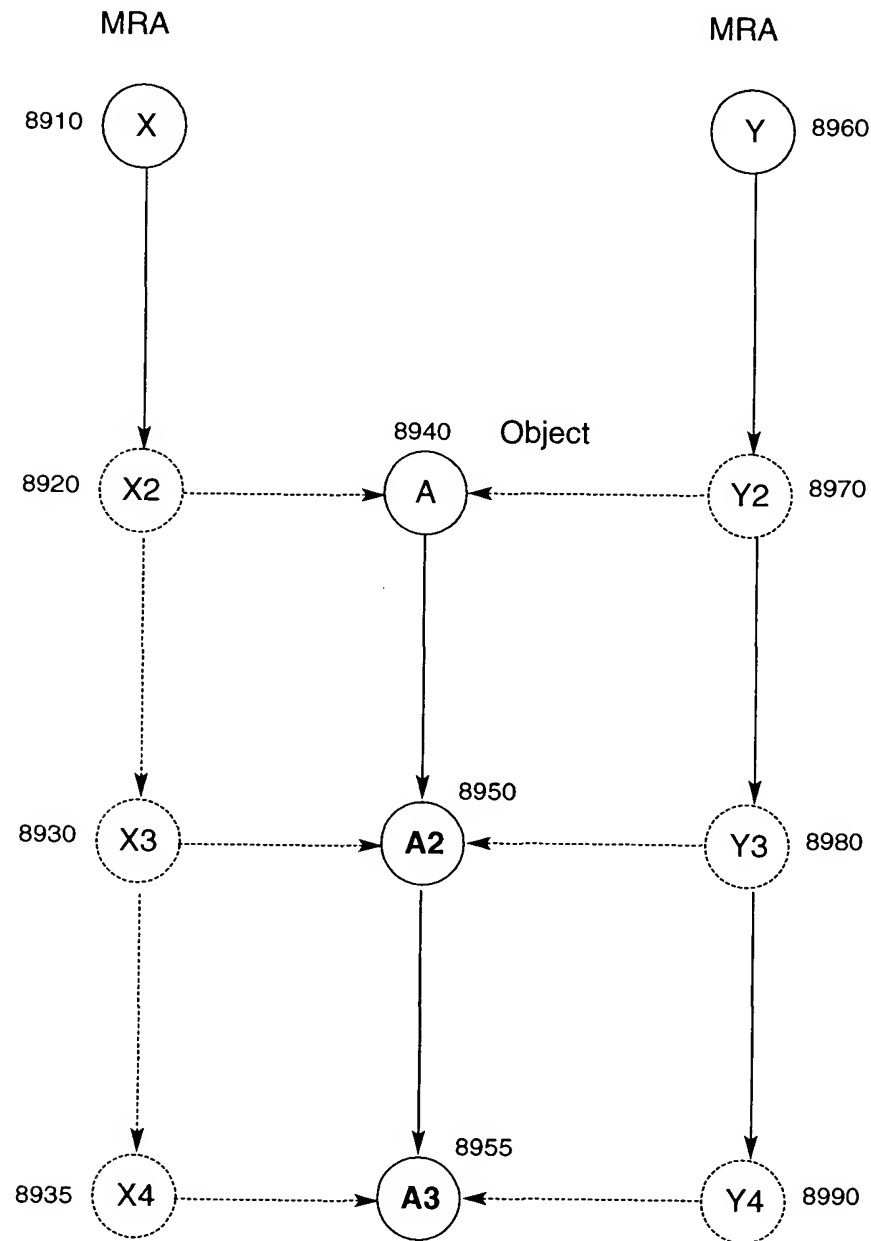
Fig 90: Remote Exploration: Initial Tracking of Multiple Objects With Multiple Micro-MRAs
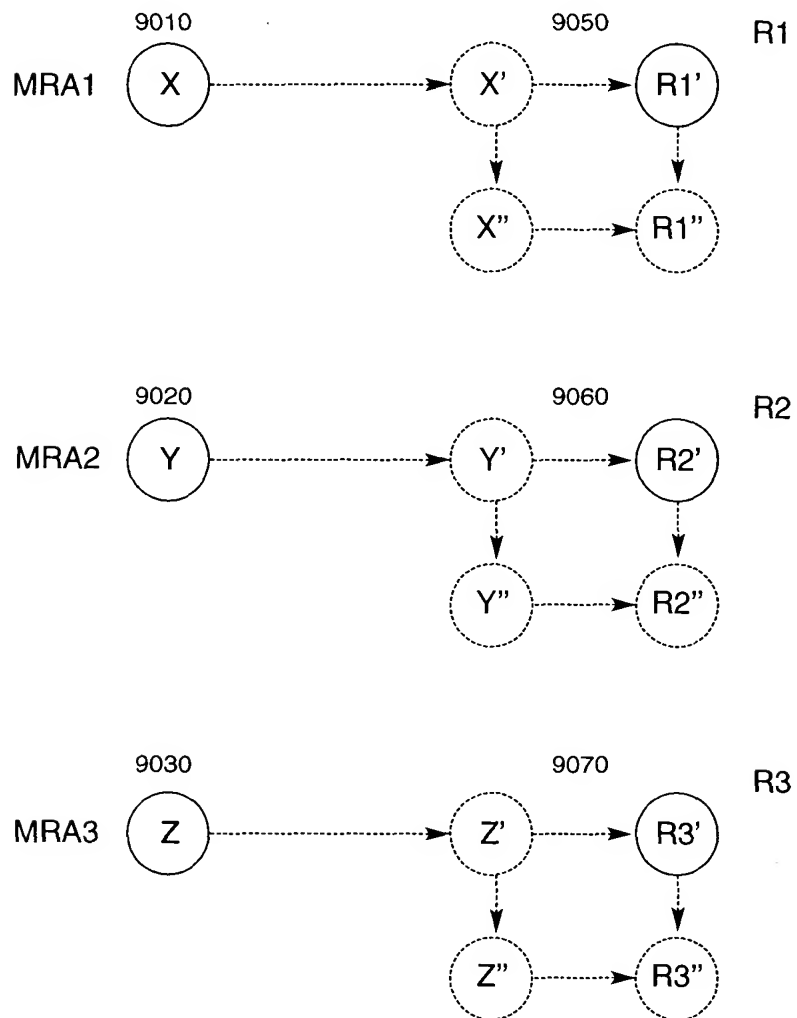
Fig 91: Sentry Action - Limited Perimeters - Defending Multiple Objects With Multiple MRAs
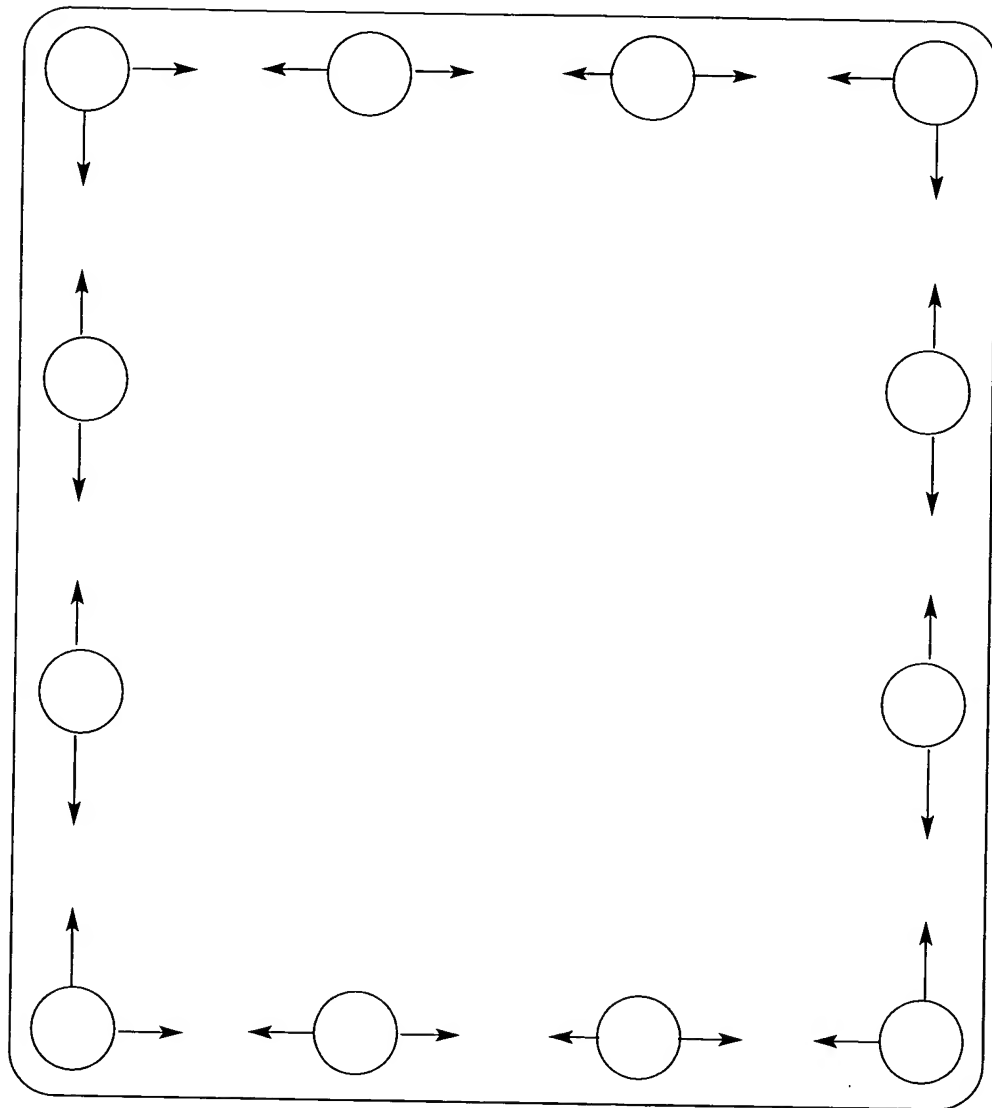
Fig 92: Cinematography - One Mobile Object (or Cluster of Mobile Objects) Sensed and Tracked with MRAs
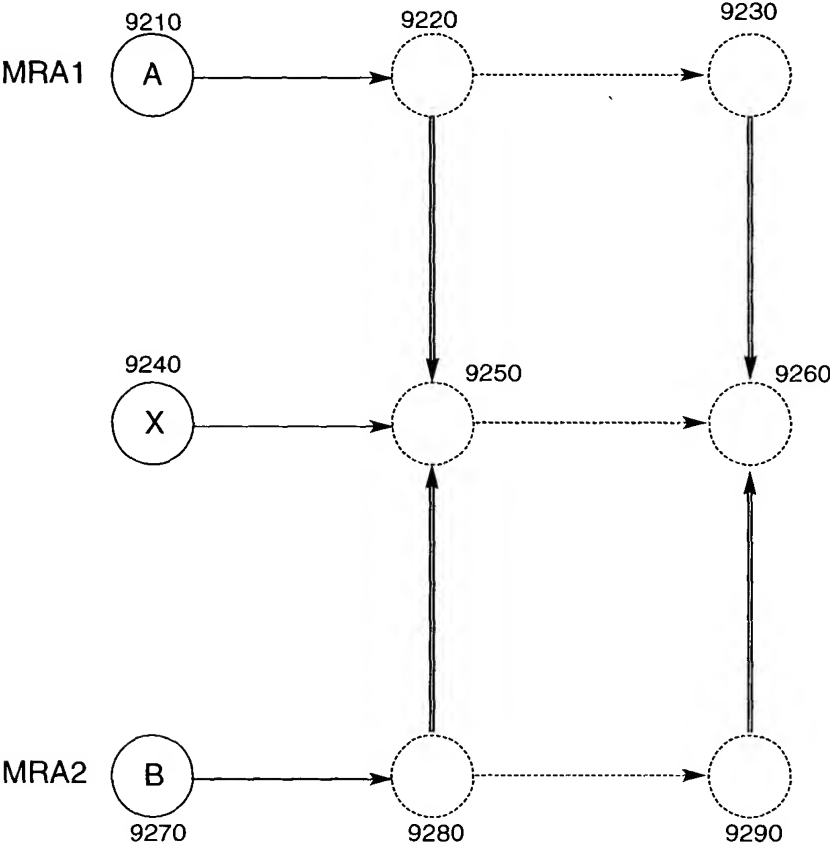
Fig 93: Toxic Site Cleanup - Static Cleanup Within Land Perimeters by Multiple MRAs

(I)

9310

9320

A-type MRA

(II)

9330

9340

B-type MRA

(III)

9350

9620

C-type MRA
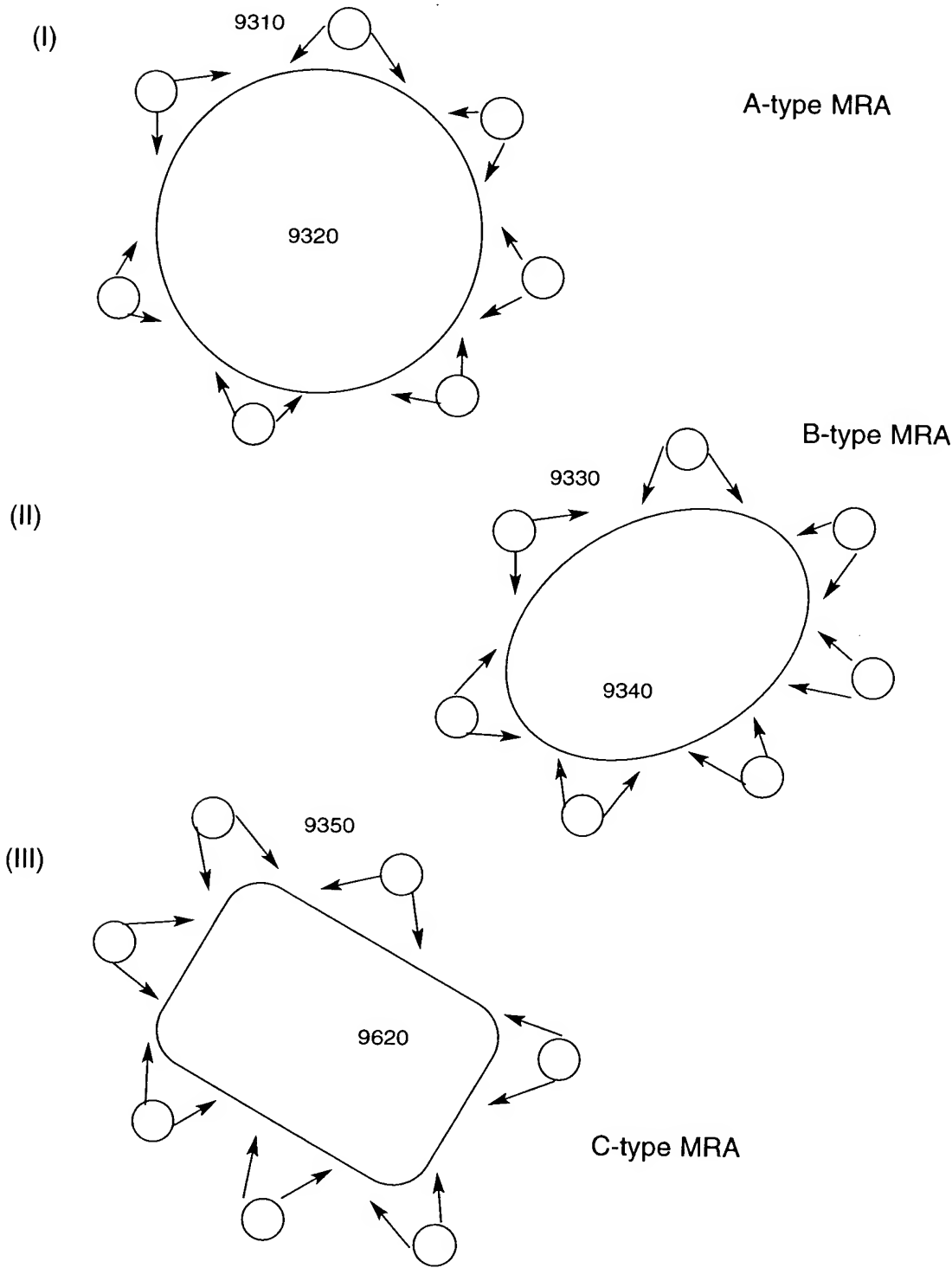
Fig 94: Oil Spill: Dynamic Cleanup Within Limited
Hydro Perimeters by Multiple MRAs

(I)

9410

9420

(II)

9430

9440

(III)

9460

9470
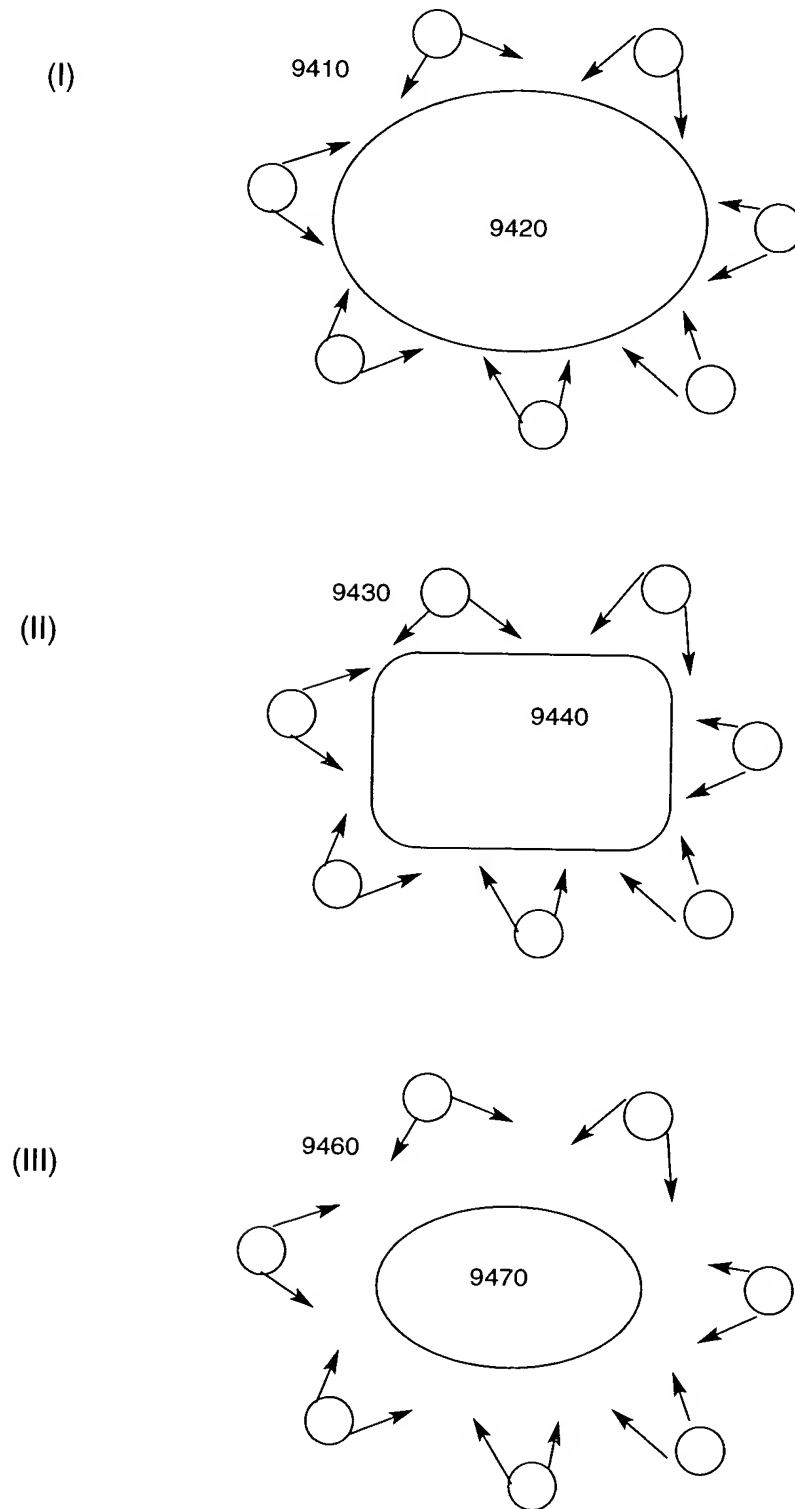
Fig 95: Fir Fighting - Dynamic Interaction With Complex Environment by Multiple MRAs

9510

9520

9530

9540

9550

9560
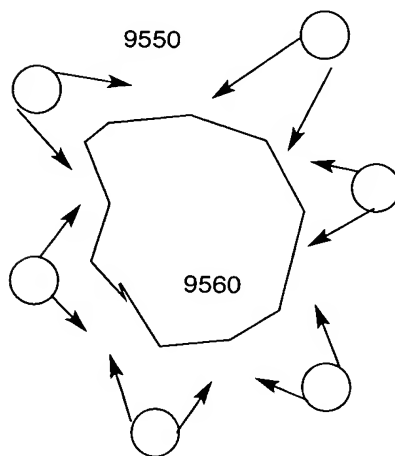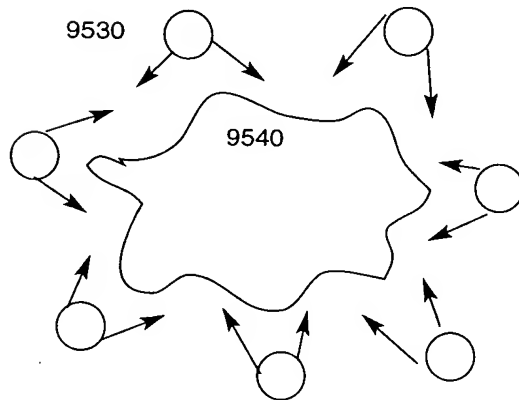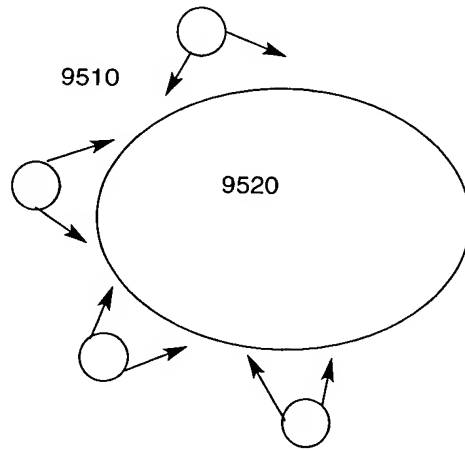
Fig 96: Manufacturing Production:
Object Creation Using Multiple MRAs

9610

A

9620

9630

D

9640

B

C

9650
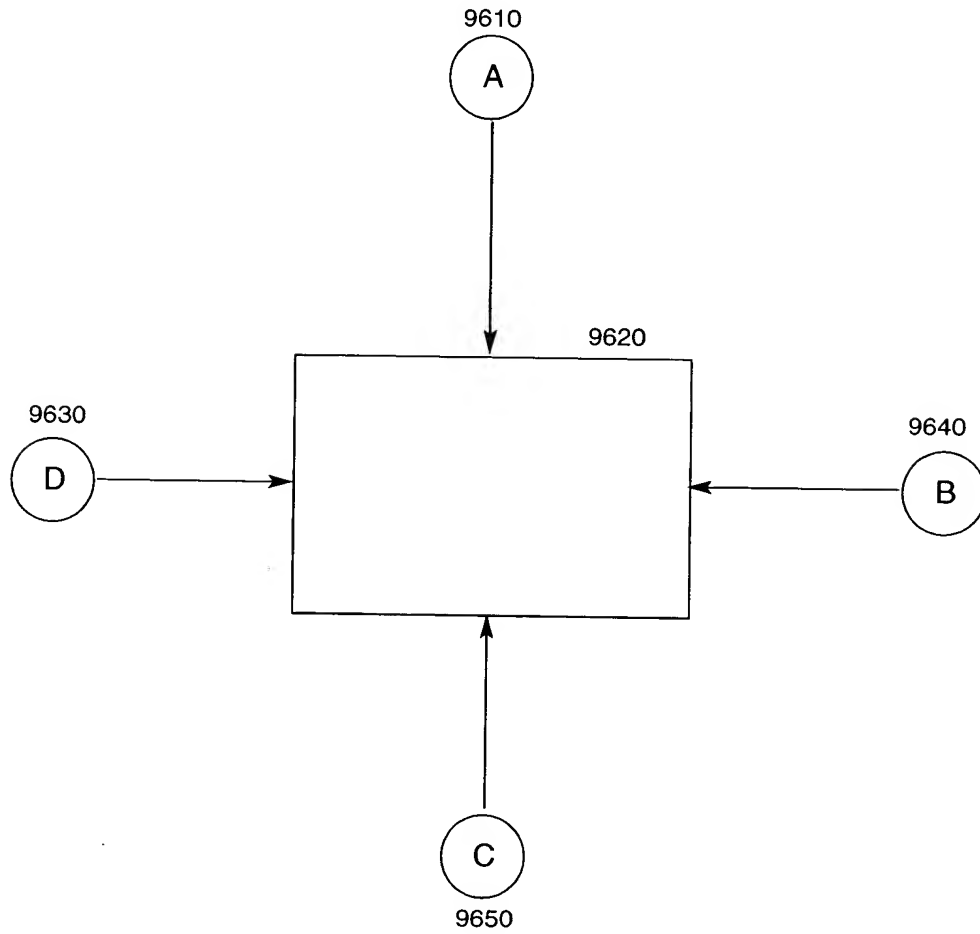
Fig 97: Assembly: Combining Parts To Create Whole Object Using Multiple MRAs

9710

9720

A¹

9730

B¹

9740

A²

9750

B²
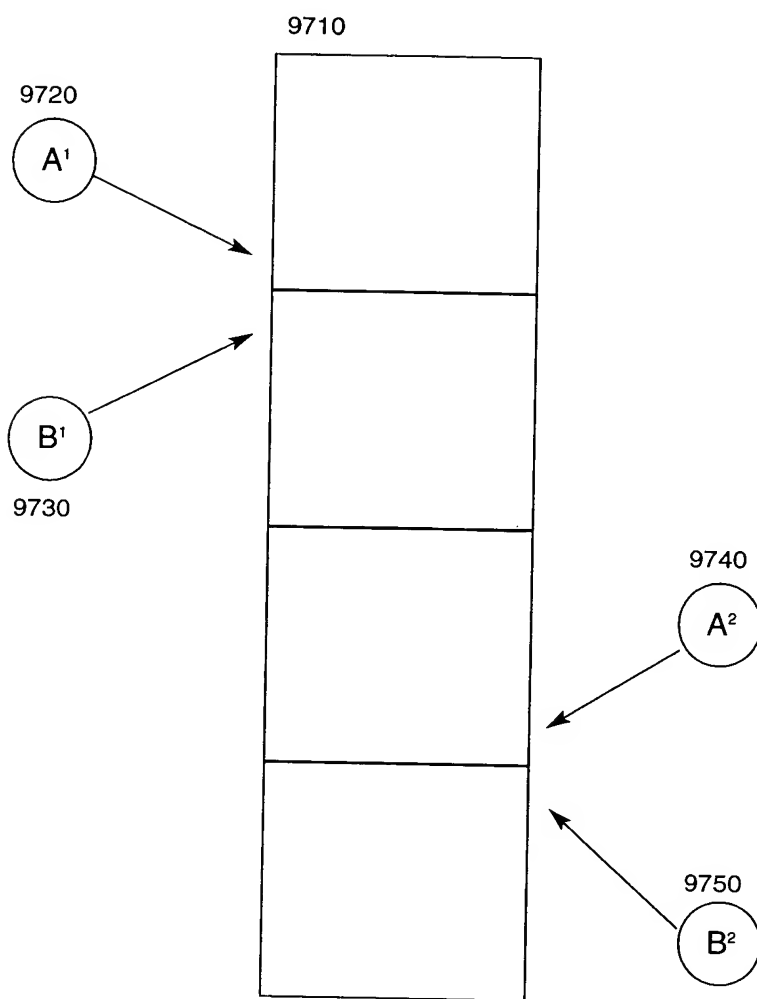
Fig 98: Building Roads: Road Creation Using Multiple MRAs

9810

A

9820

B
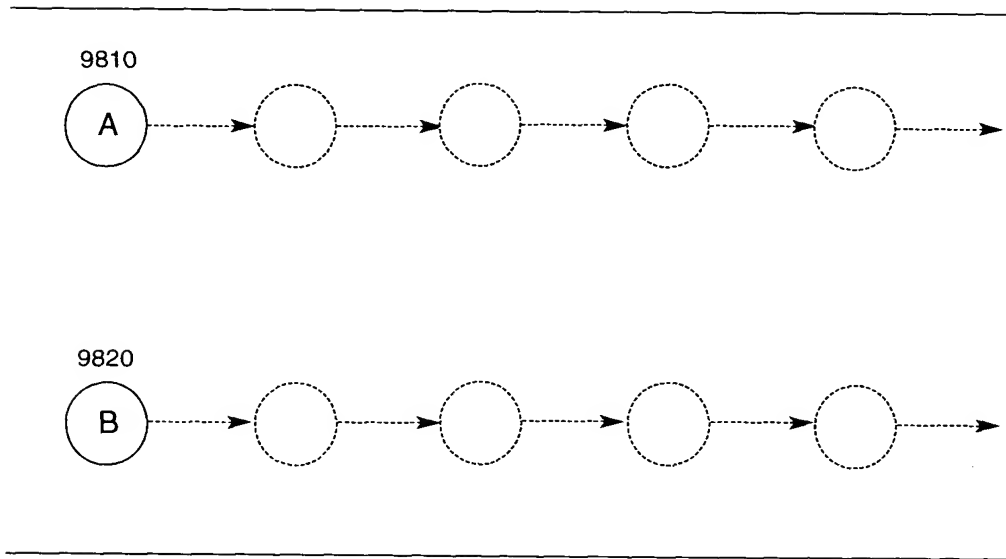
Fig 99: Surgical Micro MRAs for Trauma Intervention & Stabilization